

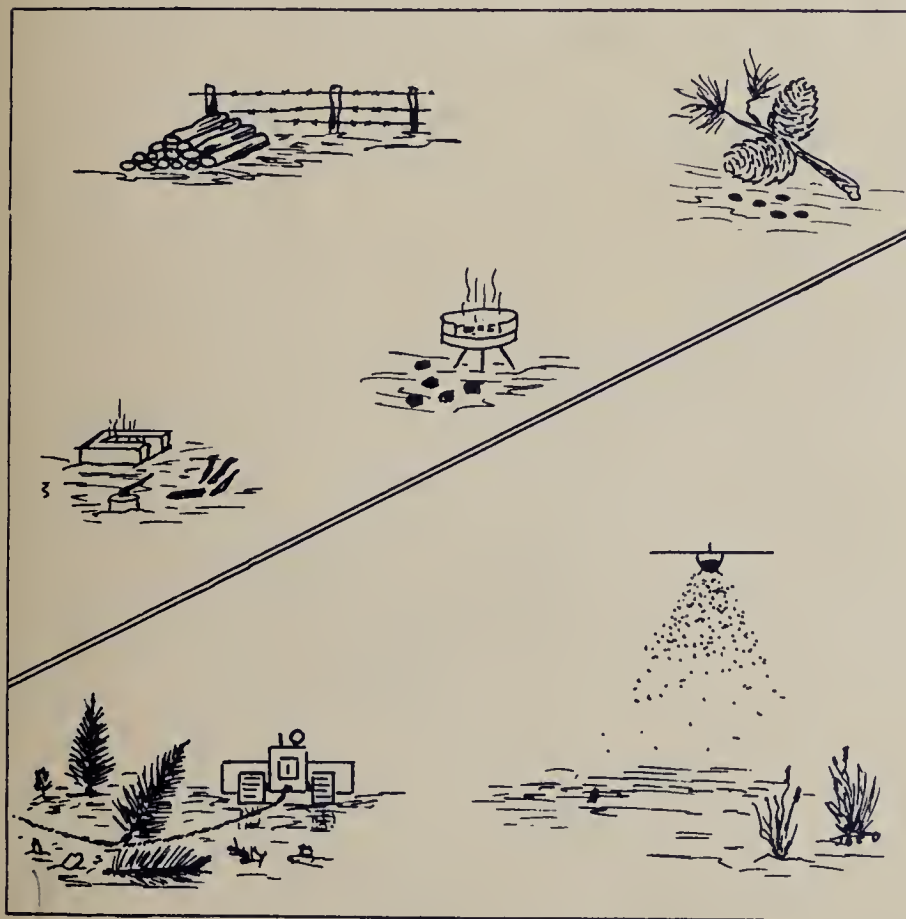


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Management Alternatives for Pinyon-Juniper Woodlands



Part B

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MANAGEMENT ALTERNATIVES FOR
PINYON-JUNIPER WOODLANDS

B. Economic Phase

"The Economics of Pinyon-Juniper Management"

Allen LeBaron

with

T. Glover and R. Marasco, Research Assistants

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Logan

March 1, 1966

PREFACE

The genesis of the research reported in this volume and in the volume entitled "Ecology of the Pinyon-Juniper Type of the Colorado Plateau and the Basin and Range Provinces", was in the deliberations of Dr. Russell Lloyd (formerly Chief, Branch of Range Studies, Bureau of Land Management) and Dr. N. K. Roberts, then Chairman, Center for Social Science Research on Natural Resources, Utah State University. Early in April, 1963, the Bureau of Land Management formally requested the Director of the Utah Agricultural Experiment Station to explore the possibility of developing and conducting a project leading to better management of the pinyon-juniper woodlands. Five objectives were originally established by the Bureau of Land Management: (a) to develop ecological criteria for classification of pinyon-juniper sites; (b) to develop the minimum essential ecological data needed for management under various alternatives; (c) to clearly identify the multiple products of woodland ranges and to determine the competitive - complementary - supplementary relationships among them; (d) to assess economic value of the multiple products; and (e) to make economic analysis of the various management alternatives and woodland uses on the major sites.

A memorandum of understanding was signed in the middle of June, 1963 and a project work plan, drawn up by Dr. Roberts and Dr. T. W. Daniel, (Forest Science Department, Utah State University) was adopted later that summer. Dr. Roberts was the over-all project coordinator; Dr. Daniel was the ecological phase leader; in December 1964, Dr. A. LeBaron was made economic phase leader.

This volume reports on objectives d, e, and part of c. It is hoped that they have been attained. In certain instances, economic analysis has been greatly hampered by the lack of knowledge concerning certain physical relationships which underly, for example, wildlife or watershed benefits from pinyon-juniper woodlands; the cross-sectional nature of the available ecological data seriously restrict the kinds of models which can be developed for estimating the benefits from various conversion practices.

In addition to the two volumes comprising the project report, attention is directed to the research paper submitted by W. Meiners (assigned by the Bureau of Land Management to the ecological team during the first portion of the study) submitted in partial fulfillment of the requirements for a Master's Degree granted by Utah State University, June 1965, entitled: "Some Geologic and Edaphic Characteristics Useful to Management Programming Within the Pinyon-Juniper Type". Terrence Glover and Richard Marasco also have had Master's theses accepted by the University: "Estimating Forage Production Following Pinyon-Juniper Control: A Probabilistic Approach" and "Selecting Optimum Conversion Practices in the Pinyon-Juniper Type" (both, August, 1966). Short accounts of these latter topics appear in Proceedings of Western Agricultural Economics Association meeting, 1966. A forthcoming Master's thesis by H. E. Isaacson is titled: "The Relationship of Vegetative Understory to Pinyon-Juniper Canopy Cover."

Office records obtained by the economics study group from various land management agencies are linked to control sites visited but there may be inaccuracies both as to project identification and treatment practice. In some instances the apparent treatment was

at variance with office records and dates. For example, areas supposedly seeded were barren of introduced species; machinery appeared to have been used in areas reported as hand-chopped; or what were clearly tree control areas were identified by agency personnel as spraying projects, etc. All ecological plots are thought to have been located accurately to the quarter-section, but difficulty was still encountered in determining the exact agency identification of all projects visited. In one instance project records indicated a location 50 miles from the actual site; juniper posts were reported to have been cut from an area containing pinyon and ponderosa pine.

An appendix to this volume lists all ecological study plot locations. In addition, those plots adjacent to pinyon-juniper control or eradication sites are further identified by agency, local name or project number.

Dr. E. B. Wennergren, Director
Economic Research Institute
Utah State University

Note: All data in Parts A and B of this special report are preliminary and may be subjected to further scrutiny and interpretation by the Utah Agricultural Experiment Station and the Economic Research Institute.

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1. ECONOMIC PHASE ACKNOWLEDGMENTS AND INTRODUCTION

The assumption underlining the present study is that only maximization of economic values is important in management decisions. This could hardly be true in real life and does not mean that the Bureau of Land Management or any other agency should eschew other criteria. But, as a first approximation for assessing benefit potentials, the assumption offers pragmatic advantages: inconsistencies in programs or the costs of foregoing alternative economic returns are highlighted; evaluations couched in economic terms have fair political acceptability; it is possible to systematically impose sociologic or other non-economic considerations upon any initial calculations. No other single management goal confers the same advantages with respect to project planning.¹ This is because only economic evaluations share a common measuring denominator (money units) to which reference can be made in disparate circumstances.

The explicit goal chosen is that it is worthwhile for land management agencies to adopt those actions which will maximize receipts at current sales prices. Where demand elasticities will permit, stumpage and other charges might be raised; conversion projects exhibiting the highest internal rates of return will be selected

¹For example, there is no particular reason why an objectively measurable goal expressing (say) an ecologic optimum could not be formulated, but is there an objective method to weigh it against other alternatives?

first.² This view might seem to conflict with accepted notions about marginal cost pricing. And since the trees are "already there" a temptation exists to draw an analogy with a free good and thus to advocate zero pricing. But this notion is only reasonable if it is somehow assumed that all land management costs fall into the category of fixed investments. Actually many costs can be regarded as variable although it is true that at any given moment some cannot be attributed to specific management activities. This is all mainly a question of time periods employed in analysis. If periods at least as long as a year are chosen, salaries of many staff positions are variable. Then, in terms of totals, annual receipts from certain management activities in the study area under consideration would undoubtedly fail to cover the marginal costs of annual salaries for district personnel directly or indirectly linked to management of the resources in question (3, Administration, Finance and Personnel). Thus, unless flexible pricing policies continue to be employed there may be little hope of even covering marginal costs.

Nothing that has been said is substantially at variance with what generally has been administrative policy of all agencies: an attempt to realize whatever income can be obtained from pinyon-juniper woodlands has been, in fact, the general administrative policy of all agencies. But heretofore the value of the products for commercial purposes has never seemed very great, especially in areas where "invasion" is a problem. The trees are thought by many to be un-

²The effect of a "bid" system when selling Christmas trees, for example, is to maximize receipts.

desirable and the opportunity to convert woodland to grassland has often been seized (Cf. 1, p. 51-52; 2, p. 1)

Nevertheless, the practice of simply eradicating the trees may seem to imply an absence of management for in a sense the resource seems "wasted" or "lost". At the heart of this is probably the realization that eradication effectively eliminates further consideration of a given site as a producer of a renewable tree resource. Therefore, the view that some more generally beneficial use "ought to be obtained" from an existing resource which covers so vast an area has great appeal. The conclusions reached by way of the present study however, are not encouraging. Unless some totally new demand presents itself, the existing tree uses are likely to persist at more or less present levels into the foreseeable future. In general, the only reason to expect that demand will not continue to be set by known market forces would be because private industry or land management agencies actively undertake development of viable new technologies, products, or outlets for pinyon-juniper wood.

On the other hand, the conversion of pinyon-juniper woodlands to grasslands is well within the control of management agencies; for all practical purposes the agencies can control the demand for tree removal. This follows from the fact that many of the variables affecting general grazing markets can be altered approximately at will. Thus, the major pinyon-juniper management option is that of converting woodlands to rangeland. For this reason, a major portion of the economic research effort has been directed to the means of evaluating this option.

A great number of people contributed their time and advice and made available collected records for economic analysis. In the course of the 1964-65 field seasons the economic research team obtained data from many ranger districts, all forest supervisors, Bureau of Indian Affairs Area and Agency offices, and all Bureau of Land Management district offices in western Colorado, western New Mexico, northern Arizona, Utah and eastern Nevada. It is to the personnel in all of these agencies that the greatest debt is owed. While the Regional Foresters in Regions II, III, and IV all forwarded data concerning tree removal projects, reports of the enormous amount of eradication work carried out by the Albuquerque office were especially helpful.

Research plans were improved by consultation with Wayne Cook, A. C. Hull, A. Bleak, Perry Plummer, Donald Jameson, Fred Lavin, Richard Aro, John Hanks, Gaylen Ashcroft, and Arlo Richardson. Bernard Oury at North Carolina State University provided the program used to compute the weather indices. Members of the ecological team headed by Dr. T. W. Daniel (H. Isaacson, E. Eberhard and R. Rivers) strived to satisfy the data demands placed upon them. Arvel Hale, Terrance Glover, and Richard Marasco, graduate assistants, carried out much of the economics field work and were responsible for statistical analysis and econometric design contained in the "conversion" section.

The subject matter of Part B divides itself naturally into two portions, one dealing with conversion of woodlands to grasslands, the other with pinyon-juniper products. Since even relatively minor decisions about products must hinge upon the answer to the question,

does it pay to convert?, the potential benefits from tree eradication are considered first. Estimating procedures are developed that provide the fundamental present worth figures to be juxtaposed with the values of various wood products.

Appendix A is a listing of all ecological plot locations and (where applicable) the adjacent tree control sites. This information will prove helpful in interpreting part of the material contained in Part A of this report.

REFERENCES

- (1) Aro, R. S. Conversion of Pinyon-Juniper Woodland to Grassland, U. S. Geological Survey, Water Resources Division (Denver: 1965 preliminary draft), 129 p.
- (2) Evatz, E. R. and F. C. Shields. Vegetation Management - Chaining Undesirable Trees on Public Lands in the Western U. S. Staff report, Durango District, BLM, June 30, 1964, (typescript) 7 p.
- (3) United States Government. Public Land Statistics, U. S. Dept. of Interior (Washington: G.P.O. 1963, 1964, 1965).

2. THE CONVERSION DECISION

In this section, the choice of whether or not to convert a portion of pinyon-juniper woodlands to grassland is treated as a question isolated from other economic problems. No explicit allowance is made for any benefits other than increased forage. This does not mean that other benefits are not worthwhile, but/they can be readily introduced into the decision process as deemed appropriate. Calculations should also be influenced by losses of potential product sales. Such estimates can be treated as additional costs, less any salvage value.

The section commences with a summary of the apparent economic results of a number of conversion projects. Following this, the hypothesis that conversion costs or benefits correlate with site indexes is tested. And finally, models to predict benefits in selected areas and to optimize on conversion technique are presented.

2.a. Historical Results

Costs of pinyon-juniper conversion and reseeding projects on public lands covered by the study team were obtained from BLM district records. In the course of their survey, the ecological team visited as many of these sites as possible. In addition, the costs of a large number of Forest Service and BIA projects were obtained.¹ The ecological team was able to visit a number of these.

¹In general, these records were not as detailed as those obtained from BLM sources. Fortunately, in many instances, projects did not include reseeding operations, so breakdowns were less important.

For bookkeeping and reporting purposes, costs of projects are allocated in a number of ways. There is no consistency between agencies and, where methods of budgeting have altered, there are variations within an agency when early projects are contrasted with recent experience. Thus certain arbitrary decisions had to be made about what to include for present purposes. The most important was the decision to consider only out-of-pocket costs. Overheads are ignored. All costs that were known or thought to be covered by contracts fell into the former category. Supervisory costs were ignored. Projects partially or wholly conducted on force account were especially troublesome. Those that were clearly part contract-part force account were identified and some allowance is included for force account labor. An attempt to separate overheads from other costs on purely force account projects was abandoned as impossible. Total recorded agency costs are used in such cases.

Where reseeding was accomplished in conjunction with tree removal, fences were often a part of the project. Sometimes fencing was covered by a separate contract, but its existence was not always obvious from perusal of project files. In any case, treatment of fencing costs creates a dilemma. Some projects, benefit from "natural" fencing. Others require a small amount. And still others require a lot. Even if such projects are otherwise similar, their costs vary tremendously and make comparisons difficult. On the other hand, in some cases, if there is no protection, how can benefits be expected to materialize? Since there seemed to be no way to work a fencing variable into the treatment cost prediction models and since inclusion of fencing costs rendered comparisons so difficult, fencing cost was also ignored.

The data in table 2.a.1. should be compared with that of tables 6.c.3. and 7.c.2. of Part A of this report. These list local project names, whether seeded, other treatments, before and after grass production, tree counts, kill percentages, and predictions of eradication longevity for various canopy percentages. The increases in observed grass production have been valued according to best estimates of season of use. Values employed are those shown in footnote (v) of the table, and are based mainly upon table 4 of Roberts and Topham (22). Readily available information about local range permit values was used to improve the figures somewhat. Data in the source quoted is designed to show the social value of an animal unit month of grazing under particular conditions. That is, it includes an allowance for the capitalized value of range permits. The values reported differ according to type of grazing and season of use. It is also possible to value the forage increase purely in terms of cash recovered by the agencies involved, namely in terms of the grazing fees. A few examples have been calculated on this basis and are shown for comparison purposes.

In general, the computed internal rates of return do not allow for the loss in forage when ranchers accept deferment during the two or three seasons necessary to establish grass seedlings. Again, for comparison purposes, a few examples have been calculated, using the formula shown in n.1, p. 19 below.

Since the cost data are subject to interpretation and since the forage increases had to be obtained from the results of growth in one particular season (or because the type or time utilization assumed may not be correct) readers may wish to substitute slightly

Table 2.a.1. Average internal rates of return for a number of pinyon-juniper conversions

Agency and project number	Ecological team plot number	Site index	Field season	Force Account, Mixed, Contract-Permittee ^e	Cost/acre ^e	Lbs. of increased forage/acre	Season of use and type ^v	Value/AUM \$ (social)	Average Internal Rate (i)				Average (i)-32 yr w/2 yr deferment (social value)	
									Social Value		Grazing Fee (33¢)			
									20 yrs	30 yrs	20 yrs	30 yrs		
Escalante-Sevier Province														
U2 - R-156	256	16 65	F	}	5.36	700	SF -C	.574	8.2	10.1	-1.7	1.9		
175 & 178 } 175 Redo }	256c	-- 65	M		13.75	413	SF -C	.339	-6.0	-1.9				
R-12 S.30	258	15 65	C		}	18.14	336	SF -C	.276	-9.5	-4.6			
R-12 S.25	258c		C				376	SF -C	.308	-8.5	-3.75			
U3 & 10 -														
379-399	262	19 65	F		20.04	545	SF -C	.447	-6.7	-2.5				
379-399	176	14 64	F		20.04	521	SF -C	.427	-7.0	-2.7				
404	268	21 65	F		9.69	1,021	SF -C	.837	6.0	8.1				
416	269	-- 65	F		12.28	1,184	SF -C	.971	5.0	7.0				
413	261	20 65	F		8.64	1,164	SF -C	.954	9.0	10.5				
430	266	18 65	F		9.95	790	SF -C	.648	3.0	5.1				
430	266c	-- 65	-		9.95	1,115	SF -C	.914	7.6	8.9				
433	267	21 65	F		4.28	149	SF -C	.122	-4.9	-1.0				
437	272	24 65	F		9.35	1,417	SF -C	1.160	11.0	+12.0				
437	273	-- 65	-		9.35	1,775	SF -C	1.460	14.5	15.2	2.2	4.3	12.0	
458	274	21 65	F		12.46	1,103	SF -C	.904	3.9	6.0				
468	263	18 65	F		10.60	1,525	SF -C	1.251	10.1	11.8				
468	264	18 65	F		10.60	1,491	SF -C	1.226	9.9	11.1				
468	173	19 64	F		10.60	110	SF -C	.092	-13.0	-7.0				
R-55	378	-- 65	M		13.70	908	SF -C	.745	-.7	3.2				
APW 72	255	20 65	C		16.45	1,229	SF -C	1.007	2.0	3.2				

	APW 72	255c	-- 65	-	16.45	707	SF -C	.580	-3.3	0.3			
	APW 72	182	15 64	-	16.45	762	SF -C	.625	-2.5	0.8			
U4	- 485	282	24 65	P	9.46	644	SF -C	.528	1.1	3.8			
	R-1	275	19 65	F	9.15	364	WD -C	.495	0.9	3.5			
	R-1	275c	-- 65	F	10.64	1,026	WD -C	1.395	11.9	11.0			
	R-75	270	15 65	F	3.27	394	SF -C	.323	8.1	9.0			
	R-75	136	22 64	F	3.27	760	SF -C	.623	18.5	19.1	4.2	7.3	
	R-187	379	26 65	C	15.09	1,598	SF -C	1.310	6.0	8.8			
	466	276	15 65	F	2.76	371	SF -C	.304	9.1	11.8			
	466	140	14 64	F	--	41	SF -C	.034	-11.0	-5.3			
N1	- R-442A	388	22 65	C	1.06	132	SF -C	.108	8.0	9.7			
	R-442B	388c	25 65	C	1.27	726	SF -C	.595	45.0	45.5			
N5	- 432	386	26 65	-	6.76	628	SF -C	.515	4.2	7.2			
	477	278	19 65	C	5.31	17	SF -C	.014	-28.0	-12.0			
	R-7	277	22 65	C	4.80	280	SuF-C	.323	3.2	6.3			
	R-10	387	28 65	C	4.80	536	SF -C	.439	6.3	9.0	-2.8	-.6	
	R-11	281	-- 65	C	4.80	41	SF -C	.034	-20.5	-8.0			
	R-6	385	26 65	M	9.82	754	SF -C	.618	2.3	5.7			
	R-478	279	17 65	M	18.29	808	SuF-C	.905	0.1	3.8			.08
La Sal Province													
U8	- R-11	323	-- 65	F	5.14	805	SuF-C	.902	16.4	17.9			
	R-11	193	23 64	F	5.14	127	SuF-C	.142	-5.2	-1.2			
	R-11	193c	-- 64	F	5.14	625	SuF-C	.699	11.9	13.8			
	R-52	323c	-- 65	C	6.96	1,719	SF -C	1.409	19.7	19.0			
	Pine Springs	322	21 65	M	9.29	900	SF -C	.738	5.0	7.0			
	Pine Springs	322c	21 65	M	9.29	1,090	SF -C	.894	7.9	9.0			
	R-40	197	19 64	F	1.05	250	SF -C	.206	19.1	20.0			
	R-76	325	-- 65	M	10.42	263	SF -C	.216	-7.4	-2.9			
	R-77	324	-- 65	M	5.54	1,475	W -S	2.005	36.0	27.0	10.0	11.6	
U7	- R-89	293	16 65	M	14.19	648	SuF-C	.725	0.25	4.2			
	R-137	296	-- 65	M	8.33	1,385	WD -S	1.884	22.0	22.5	8.0	9.8	18.2

R-137	7	19 64	-	8.33	638	WD -S	.867	8.2	9.9			
R-198	3	16 64	M	7.06	68	WD -S	.092	-10.5	-5.1			
U5 - 435	294	-- 65	F	17.69	1,044	SF -C	.856	-0.3	2.8			
435	167	26 64	-	17.69	695	SF -C	.562	-4.0	-0.4			
44	332	20 65	C	5.70	136	SF -C	.111	-7.7	-3.2			
69	295	19 65	C	9.82	962	SF -C	.789	5.0	7.2			
U11- R-29	328	22 65	M	19.62	963	SF -C	.790	-2.0	1.3			1.0
Mackel P.	326	19 65	M	6.00	256	SF -C	.210	-3.4	0.2			
Sheep F.	330	23 65	F	8.26	1,008	SF -C	.827	7.9	9.8	-2.0	1.7	
R-42 #2	327	20 65	C	22.39	548	SF -C	.449	-7.4	-3.0			
R-42 #2	130	20 64	C	22.39	367	SF -C	.301	-10.3	-5.1			
U6 & 9 -												
261	391c	24 65	M	5.12	819	SF -C	.672	11.0	12.9			
277	391	24 65	C	6.24	970	SF -C	.795	11.3	12.6			
279	406	21 65	M	6.51	662	SF -C	.543	5.9	7.8			
292	305	21 65	C	6.19	569	SF -C	.467	4.1	6.2			
308	298	19 65	M	8.24	523	SF -C	.429	0.3	3.2			
308	299	-- 65	-	8.24	402	SF -C	.330	-2.0	1.3			
316	297	20 65	C&M	8.70	541	SF -C	.444	0.2	3.0			
324	301	26 65	C	4.04	873	SF -C	.716	17.0	17.9			
R-3	307	16 65	C	6.68	1,170	SD -C	1.099	15.8	16.4	1.8	4.0	
R-4	318	-- 65	M	6.71	896	SF -C	.735	9.0	10.4			
R-4	39	18 64	-	--	244	SF -C	.200	-4.5	-0.8			
R-18	306	27 65	C	6.49	1,066	SF -C	.874	12.0	13.2			10.3
R-66	303	22 65	C	5.76	669	SF -C	.549	7.1	8.9			
R-66	304	22 65	C	5.76	333	SF -C	.273	-0.5	2.7			
C1 & 6 -												
499	319	15 65	M	2.94	438	WD -C	.596	19.4	20.1	2.7	5.0	14.5
510,511,512	320	16 65	C	4.43	232	SF -C	.190	-1.7	1.2			
510,511,512	321	18 65	C	2.00	49	SF -C	.040	-7.5	-3.0			
R-82	145	23 64	C	2.39	287	SF -C	.235	7.7	9.2			
R-96	143	17 64	C	8.17	116	SF -C	.095	-16.6	-5.5			

C7 - R-7 #1	348	-- 65	C	9.14	893	SF -C	.732	5.0	7.5			
R-7 #1	150	24 64	C	9.14	561	SF -C	.460	0.2	3.0			
R-7 #2	348c	26 65	C	9.43	1,213	SF -C	.995	8.1	10.0			
R-7 #2	151	23 64	C	9.43	636	SF -C	.521	1.0	3.6			
R-263	347	24 65	C	7.81	951	SF -C	.780	7.7	8.9	-2.0	2.8	
C3 - 283	346	24 65	C	6.16	478	SF -C	.392	2.4	4.8			
313	344	19 65	C	3.34	118	SF -C	.097	-4.8	-0.8			
R-78 #1	343	21 65	C	5.50	402	W -S	.547	7.7	8.9			
R-78 #1	157	24 64	C	5.50	703	W -S	.956	16.9	17.8			
R-78 #2	157c	-- 64	C	5.50	567	W -S	.771	12.2	14.0			
R-137	340	19 65	C	5.08	443	SuF-?	.496	7.7	9.4			
R-138	339	19 65	C	4.94	33	W -S	.044	-13.0	-7.0			
R-278 #1	160	22 64	C	3.19	23	SuF-	.026	-13.5	-7.4			
R-278 #1	161	20 64	-	--	74	SuF-	.083	-6.8	-0.5			
R-277 #2	345c	22 65	C	5.07	835	SuF-C	.935	17.9	18.1	2.1	4.5	14.9
R-313	345	22 65	C	3.19	218	SuF -C	.244	4.3	6.5			
R-346 #2	342	27 65	C	6.68	99	SuF-C	.111	-8.8	-4.0			
C4 - 333	49	16 64	F	8.29	129	W -S	.175	-7.1	-2.9			
R-158	335	23 65	C	3.61	962	SF -C	.789	21.0	21.8			
R-159	337	26 65	C	3.63	821	W -S	1.116	31.0	31.0			
R-178	43	19 64	C	3.78	69	W -S	.094	-6.0	-0.9			
R-176	338	27 65	C	3.33	553	W -S	.752	22.0	22.5	5.7	6.1	
R-235	336	22 65	C	3.56	517	WD -S	.703	19.0	19.3			
R-236	334	-- 65	C	3.43	136	W -S	.185	0.7	3.4			
R-278	333	18 65	C	3.27	199	W -S	.271	5.2	6.8			
Manti - La Sal												
Peter's Point	300	24 65	C	2.25	391	SF -C	.320	13.0	14.0			
Coronado Province												
A1 - 279	283	20 65	C	3.24	48	SF -C	.039	-11.0	-5.4			
298	382	23 65	C	2.30	139	WD -S	.189	5.2	6.8			
369	288	19 65	C	3.75	141	WD -S	.192	0.2	3.0			

	374	286	16 65	C	3.05	136	SuF-C	.112	-2.9	0.6			
	374	287	24 65	C	3.05	190	SuF-C	.156	0.2	3.0			
	374	289	23 65	C	3.05	161	SuF-C	.132	-1.6	1.7			
	382	290	14 65	C	5.26	380	SF -C	.312	1.9	4.2			
	398	361	22 65	C	2.24	154	WD -S	.209	7.7	8.6			
	399	381	20 65	C	3.66	246	SF -C	.202	1.0	2.8			
	402	284	17 65	C	3.27	392	WD -S	.533	15.2	16.0	.05	3.4	10.6
	427	384	28 65	C	3.17	64	SuF-C	.072	-6.7	-1.3			
	R-33	285	22 65	C	1.44	30	WD -S	.041	-5.0	-1.0			
	R-459	380	24 65	C	1.50	28	WD-S&C	.038	-6.0	-1.7			
	R-461-376	291	20 65	C	9.19	949	WD -C	1.291	13.0	13.8			
	R-544	283	26 65	C	1.45	118	WD -S	1.604	8.9	10.1			
NM7-	356	13	16 64	C	2.72	77	SuD	.072	-5.5	-1.4			
	R-363	311	21 65	C	3.25	190	SuD	.179	0.8	2.8			
	R-364	315	20 65	C	3.25	70	SuD	.066	-7.5	-3.0			
	R-364	8	31 64	C	3.25	1	SuD	.0009	-38.0	-9.6			
	R-93	314	19 65	C	3.19	261	SuD	.245	4.2	6.1			
	R-24	309	20 65	C	5.85	282	SuD	.265	-0.9	2.1			
	R-158	312	17 65	C	5.25	74	SuD	.069	-10.5	-5.4			
	R-152	310	19 65	C	4.78	281	SuD	.264	0.9	2.8	-7.5	-3.5	.07
	R-152	10	20 64	C	4.78	30	SuD	.028	-15.5	-9.0			
	R-209	313	16 65	C	4.87	146	SuD	.137	-5.0	-1.1			
	R-208	316	17 65	C	4.96	268	SuD	.252	0.2	2.9			
	R-333	317	28 65	C	4.53	246	SuD	.231	0.2	2.9			
NM1-	1	31	27 64	C	2.89	49	SuD	.050	-8.5	-3.7			
A2 & 3 -													
	285	72	14 64	C	3.57	12	SuD-C	.013	-17.9	-10.8			
	284	59	21 64	C	3.73	234	SuD-C	.220	1.8	4.2			
Chinle													
	#1	N1C	-- 65	C	10.50	1,157	SF -S	.949	6.1	8.1			
	#10	N1	31 65	-	8.49	1,355	SF -S	1.111	11.9	12.9			

#2	N2	24 65	C	1.60	243	Y	-S	.333	20.0	20.8
#3	N3	-- 65	C	1.50	56	Y	-S	.077	0.2	2.9
Fort Defiance										
#3	N4	-- 65	C	1.50	100	Y	-S	.137	6.0	9.5
#1	N5	20 65	C	1.75	173	Y	-S	.234	12.0	13.1
#5	N6	25 65	C	1.50	191	Y	-S	.262	16.2	17.8
#4	N7	19 65	C	1.50	221	Y	-S	.303	19.8	20.0
#20, #21	N8	25 65	C	2.60	211	Y	-S	.289	9.2	10.5
#37, 38, 39, 42, 52, 53, 55	N9	20 65	C	2.00	220	Y	-S	.302	14.0	14.5
Tuba City										
#4, 5	400	19 65	M	3.17s	345	Y	-S	.473	13.9	14.8
#2	402	18 65	M	1.57s	190	Y	-S	.260	16.0	-4.0
#11	404	22 65	M	1.80s	38	Y	-S	.052	-5.0	-1.0
#12	405	26 65	M	1.80s	131	Y	-S	.179	7.9	9.0
Con-Ute	48	24 64	M	4.20	970	SF	-C	.759	17.8	18.0
Hopi #1	398	17 65	C	1.20	109	Y	-S	.149	10.9	11.9
#2	H2	-- 65	M	1.50s	308	Y	-S	.422	28.0	28.0
#4	H4	-- 65	C	3.12	130	Y	-S	.178	1.9	3.5
#5	399	17 65	C	1.20	181	Y	-S	.248	20.0	20.5
Zuni 8	Z19	24 65	F	1.25	217	Y	-S	.298	23.5	23.9
9	Z19c	-- 65	C	1.50	298	Y	-S	.408	27.5	27.7
10	Z20	29 65	C	2.28	317	Y	-S	.435	18.8	19.5
Haulapai										
1954	367	19 65	M	3.60	1,470	SF	-C	1.205	35.5	35.0
1957	370	31 65	M	4.50	1,079	SF	-C	.885	18.8	19.3
1959	371	31 65	M	4.45	614	SF	-C	.503	9.8	10.8
1962	369	29 65	M	3.87	1,005	SF	-C	.824	21.0	21.5
1963 chain	372	21 65	M	2.00	334	SuF	-C	.374	18.0	18.3
1964	368	25 65	M	3.35	1,311	SF	-C	1.075	27.3	32.5

Ft. Apache										
1739	16A	30 65	C	6.99	486	SF -C	.398	1.4	3.8	
	17A	-- 65	C	6.99	256e	Y -C	.366	-0.2	3.0	
	18A	-- 65	C	6.99	304	Y -C	.434	2.1	5.5	
327-6B	15A	17 65	C	5.58	190	Y -C	.271	-0.2	3.5	
Coconino										
Mud Tank 52	374	16 65	C	3.59	204	Y -C	.349	7.3	9.5	
Mud Tank 56	373	-- 65	C	6.00	128	Y -C	.219	-3.0	2.0	
Apache Maid	362	25 65	C	9.11	364	Y -C	.624	3.3	5.5	
Apache Maid 58	363	-- 65	C	11.81	216	Y -C	.370	-4.0	-0.4	
Apache Maid 58	364	26 65	C	11.81	388	Y -C	.665	-1.2	3.9	
Angell	366	23 65	C	1.58	272	Y -C	.466	29.0	29.0	
Cosnino	365	31 65	C	1.20	286	Y -C	.490	40.0	41.0	
23N-8E, S16	52	29 64	C	--	186	Y -C	.3188	--	--	
Kaibab										
Smoot Lake (1)	376	26 65	C	3.04	185	FW -C	.247	5.0	7.1	
Dog Knobs	375	23 65	C	6.79	292	FW -C	.389	1.3	3.9	
Ryan 1960	360	-- 65	C	8.57	488	FW -C	.651	4.2	6.1	
Ryan 1964	359	21 65	C	--	920	FW -C	1.230	--	--	
39N-1E S20	133	21 64	C	--	533	FW -C	.711	--	--	
38N-1W S13	134	21 64	C	--	0	FW -C	--	--	--	
Sitgreaves										
Gvt. Tanks	S-13	19 65	C	5.30	296	Y -C	.507	7.2	9.2	
West Sundown	S-11	24 65	C	7.00	311	Y -C	.533	4.5	6.1	
Dobson	S-12	23 65	C	8.79	399	Y -C	.684	4.9	7.9	
Linden-Fence	S-10	18 65	C	2.50e	167	Y -C	.286	9.8	11.9	
Ortega Lake	S-14	-- 65	C	3.50av	410	Y -C	.702	19.9	20.0	
Ortega Lake	23	18 64	C	8.00av	131	Y -C	.224	-5.0	-1.1	

^vThe following values have been utilized for the seasons, locations, and animal types shown:

Lbs. air dry forage/ AUM	Season	Value of Fee & Permit		
		BLM	BIA	FS
1,000	Spring Fall (SF)	.82		
750	Winter Desert (WD)	1.02		
1,000	Summer Desert (SuD)	.94		
1,000	Summer (S)			1.80
875	Summer Fall (SuF)	.98		
875	Year Round (Y)	1.40	1.20	1.50
750	Fall Winter (FW)	1.00		1.20

^eEstimated

different figures. If the calculation procedure detailed below is followed, satisfactory results will be obtained.¹

The average internal rate of return of any investment is defined as that rate of interest which will make the discounted net annual benefits equal original costs. As future maintenance costs have been taken to be nil, annual net benefits in the cases studied are simply the value of increased forage production. This value varies from year to year in real life but the value computed here is assumed to be an average over the life of the project.

But what should be established as the life of a project? This is a question that lacks a definitive answer. Some researchers have used averages of historical experience (12). Others claim that seedings can be maintained indefinitely; all that is required is correct management (6).

The truth lies somewhere between. Despite excellent management, conversions with less than 100% tree kill will be subject to "regrowth" and invasion. Even where the downed trees are windrowed, seedlings may become established. In any case, once tree canopy cover reaches as little as 10 percent, grass production will begin to fall. This process will continue until production is reduced to low values. The longevity charts in chapter 6.c. of Part A are designed to permit some estimate of the time involved. But including data from these latter charts renders calculations extremely difficult--this will be made clear in subsection c. Given this, that management isn't always

¹ A computer program was written for the formula mentioned, but unless the equipment used is extremely fast, the iterative process required is quite expensive.

the best, and the aim of providing only comparative rather than absolute values of historical results, a decision has been made to use two time periods, 20 and 30 years.

From this point, the method of calculation is readily shown:

$$C = R \left[\frac{1 - (1+i)^{-n}}{i} \right],$$

where,

C = original out-of-pocket conversion cost,

R = value of increased forage,

n = 20 or 30 years,

i = average internal rate of return.

Rearranging, the value of C/R is computed. Allowing for some interpolation, this quotient can be located in a table of present values of an annuity by scanning across columns along the nth row. The column in which the quotient is approximated is associated with a particular interest rate. This rate is the average internal rate of return. As long as the problem can be set up in this form (i.e., deferment ignored),

$$C/R = \left[\frac{1 - (1+i)^{-n}}{i} \right],$$

it is far faster to solve by hand than to use a computer.¹

¹In the deferment case, the desired internal rate must be obtained by solving the following:

$$C = R \left[\frac{1 - (1+i)^{-n}}{i} \right] - (R+O) \left[\frac{1 - (1+i)^{-m}}{i} \right],$$

where:

O = average annual value of original grazing,

m = deferment period.

Table 2.a.1. can only be interpreted in the light of the information contained in the Part A tables mentioned earlier. The techniques and results listed in them give some insight about the levels of costs and returns shown. However, for reasons indicated earlier, it can be said that in general all costs are underestimated.

Virtually all the results detailed for the Escalante-Sevier and La Sal provinces are taken from BLM experience. For these cases, it seems that higher pay-offs have occurred in the latter province. These are the projects associated with good tree kill and low seeding costs. In the Escalante-Sevier province, gains from large grass production increases are narrowed due to the higher costs incurred for windrowing and drilling.

Force account projects would have shown up better if actual labor and other out-of-pocket costs could have been used. Still, reliance upon total recorded costs might make comparisons with out-of-pocket costs of contract jobs more meaningful. Whether or not use of force account labor and government equipment is intrinsically more or less expensive than reliance upon contracts cannot be decided on the basis of individual projects. (Given reported G.S.A. rental rates, there appears reason to suspect that use of owned heavy equipment helps to hold costs down.)

In a number of instances, 1964 plots were established on the same eradication areas as in 1965. The production increases in such examples are mostly lower. Nineteen Sixty-five was a good moisture year, especially in the La Sal province. This means the 1965 production increases may be biased upward along with net benefits.

Information about season of grazing use is not as accurate as it might be, even for BLM projects. Some especially high returns may be due to introducing the wrong choices. A lot of the Navajo reservation is grazed all year but this was modified in the light of the altitude of individual projects. All year grazing is also common in the Grants-Holbrook area of New Mexico and Arizona. Only fragmentary data about the value of grazing in the year-long situation is available. And the value on reservations is even more difficult to estimate. Thus, some of the values shown at the foot of table 2.a.1. may be quite inaccurate. Fragmentary data obtained in Eastern Arizona suggest that the social value of grazing, in what would otherwise be similar situations, is greater there than in Utah and Colorado. The Navajo people are known to rent some land. This may mean that the returns from their own flocks and herds are not as good as they should be. For this reason, the social value for year-round grazing on the Navajo has been reduced below the \$1.50 level assumed for lands outside the reservation.

The poorest cost data are associated with Coronado province projects. Luckily, most Forest Service projects did not make provision for seeding. Therefore, cost breakdowns were not so important. In addition, they were mainly contract jobs, so the tabulated results may not be far wrong. A technique widely employed in this province is pushing trees with a hula dozer to obtain higher tree kills. If the trees are very plentiful, eradication costs per acre are quite high under this system. A lot of chaining, however, is still done on the reservations. And the very favorable earlier bids for pulling

trees in regions administered by the Gallup area office are indicated in the low per acre costs shown. Such low costs materially affect the level of net benefits shown, but some caution is especially necessary when evaluating these BIA results. Many of these used Indian labor for seeding and the costs of such work are not recorded. This is especially true on the Navajo reservation. The returns from burning and seeding on the Southern Ute and Haulapai reservations are quite well documented and are so obviously good that high net gains are expected. A lot of trees have been pulled on the Zuni reservation, but recent costs have risen to a level of about \$2.50 per acre.

It remains to be seen whether the low-cost chaining work is beneficial in the long run. Tree kill is not always satisfactory. But even here, as Indians herd their animals, they can burn a few downed trees each day at virtually no additional cost and original kill percentages may lose their relevance. In any case, even a modest increase in air dry forage can yield beneficial results if the costs are low enough and re-invasion is not a pressing problem.

In later parts of this section, cost and benefit prediction models are presented. But as yet, these apply only to specific regions within the study area. These are the regions for which an adequate amount of data could be obtained by the ecological team. For other regions, certain modifications or approximations must be introduced. The historical results presented should be beneficial for this purpose.

2.b. Correlation of Treatment Costs, Benefits, and Site Indexes

From the very inception of the present project, one of the hypotheses to be tested has been whether pinyon-juniper site indexes will

correlate with treatment costs or benefits. While it was recognized that the probabilities of "tight" relationships were not high the obvious benefits for P-J management were enticing. Discovery of high correlations would facilitate estimates of costs and benefits merely by establishing the site index for any area in question.

Negative results were obtained in all aspects of the test, which was conducted in the following manner. Benefits were assumed to be captured in grass production as measured on the converted sites. A variable for production measured on the control plots (located on adjacent untreated areas) was also introduced. Only the eradication portion of conversion costs was considered. And this was confined mainly to BLM projects (i.e., chaining) since other treatments such as burning or pushing are not comparable.

Following some experimentation it was found that improvement in results could be obtained by segregating the data according to ecological province. Still the results are not adequate for management purposes. They are displayed in table 2.b.1.

Table 2.b.1. Correlation and Regression Analysis of Site Index as a Measure of P-J Costs and Benefits

	(r)	(r ²) ^a
Escalante-Sevier		
Index x cost	-.056	.003
Index x project production	-.161	.026
Index x control production	-.605	
La Sal		
Index x cost	.278	.077
Index x project production	.251	.063
Index x control production	.023	.005
Coronado		
Index x cost	-.383	.147
Index x project production	-.186	.035
Index x control production	.045	.002

^aNone of the regression coefficients are significant.

The low correlations involving project production and cost are not unexpected but the low values for control production might be expected to be better. The probable difficulty in this case lies in the definition of the index. An index based on tree height alone is not adequate to estimate understory production. Some allowance for percent canopy cover might help in this regard. Extending this notion to include still other site factors might help improve cost correlations as well, but this cannot be carried too far lest complexity becomes a problem. An important part of cost variation is due to factors exogenous to a particular site situation; these can never be captured by an index based on site factors, regardless of its inclusiveness.

2.c. Estimating Forage Production Following Pinyon-Juniper Control: A Probabilistic Approach

In this and the following part much of the empirical data previously used for management recommendations in Chapter 8 of Part A have been placed on a probabilistic basis. Ways to predict costs and benefits are also developed.

The analysis that follows begins by setting forth the objectives to be achieved in evaluating the tree conversion process and its associated risk. Next a theory of range grass seedling establishment is presented. The appropriate variables are identified and an "establishment" model is applied to the empirical data. A third section specifically treats weather as a major influence upon seedling emergence and forage production. A model expressed in probabilistic terms, employing the Markov property, is applied to available data to evaluate weather

index movements. Finally, having dealt with emergence, a theory is developed to explain expected forage production in the period following emergence. The parameters of the associated model are obtained from empirical data.

The paramount issue is the identification of those factors which can or cannot be manipulated to influence expected forage production. However, the important prerequisite for any increase in forage production is to obtain seedling emergence and vigorous seedlings establishment. The investment decision requires land managers to make a decision to incur control and seeding costs based on the odds they will give that successful establishment can be achieved in the future (as determined by the fortuitous variable [s]). These odds can be altered, sometimes considerably, by manipulation of revegetation techniques to help tip the balance of nature in favor of seedling emergence. Therefore, the objectives are set forth as:

1. to isolate those factors that will, when observed in a combination of quantified magnitude, determine seedling establishment.
2. to estimate the probability of weather movement.
3. to isolate those factors affecting subsequent production.

Expected forage increase is built upon the answers to two questions: (a) what is the probability that given revegetation techniques will result in initial seedling establishment, and (b) will weather patterns following establishment be such that the grass stand will endure? To formulate the establishment process define:

$\text{Pr}(A)$ = the probability of production.

$\text{Pr}(B)$ = the probability of seedling establishment where
 $0.50 < \text{Pr}(B) < 1.0$.

$\Pr(B)$ = the probability of failure in seedling establishment
 where $0 < \Pr(B') \leq .50$ and event A and B' are necessarily
 mutually exclusive.

Assuming event A (probability of production) is dependent upon event B
 (probability of establishment), the conditional production process
 can be expressed in probabilistic terms as:

$$\Pr(A|B) = \frac{\Pr(A \cap B)}{\Pr(B)}, \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and it follows by the general rule of multiplication that

$$\Pr(A \cap B) = \Pr(B) \cdot \Pr(A|B) \quad . \quad . \quad . \quad (2)$$

The probability of establishment failure is expressed as:

$$\Pr(A|B') = \frac{\Pr(A \cap B')}{\Pr(B')} = \text{null set} \quad . \quad . \quad (3)$$

Seedling Establishment

Theoretical considerations. It is generally conceded that where
 biological processes are involved in agronomic models, economic speci-
 fication is rendered extremely difficult because the assumption of
 independence among variables and fixed measurement are relaxed (15,11).
 Such is the case in the present study of range grass production.

Water serves three functions in facilitating plant growth. It
 provides a source of raw materials which the plant utilizes in the
 photosynthesis process. Water also acts as a vehicle for conveying
 chemical elements and compounds to and from the center of photosynthesis
 activity. Finally, water serves as a cooling agent within the plant
 to protect the tissues from desiccation.

Water movement is also part of the important phenomenon of trans-
 piration. This is the process by which water is passed from the plant
 into the surrounding atmosphere. The principle of flows induced by

differential solution densities is also of relevance. The external solution in this case is the atmosphere, a solution of gases in water vapor. The density of this solution is almost always greater than the adjoining cellular solutions of plants; hence, the direction of water flow is from plant to air in turn inducing flow from soil to plant. The magnitude of the existing pressure differential governs the rate at which transpiration occurs, and any factor affecting the density of either the cellular or atmospheric solution affects the rate of water flow. The density of the surrounding atmospheric solution is a function of temperature and the potential vapor pressures. The latter is predetermined leaving temperature as the causal variable in the flow of water.

Important also is the evaporation of water from or just below the soil-air interface of the soil. Water evaporation from the soil, like transpiration, is dependent upon temperature. As the water supply increases, evapotranspiration rises to a maximum depending on the environmental climate. This maximum, if reached, is called "potential evapotranspiration." Thornthwaite (25), in studies on weather crop relationships attempted measurements on "potential evapotranspiration" and found it impossible to measure. Penman (21) has since developed a more precise measure in his studies. Thornthwaite found the evapotranspiration rate to be dependent on the interdependent factors of climate, soil moisture supply, plant cover, and land management. His experiments indicated the existence of a growth inhibiting factor directly proportional to temperature.

A growth equation has been proposed by Thornthwaite by generalizing Van't Hoff's law of physics written as:¹

$$V = a \frac{bCe^{ct}}{(e^{ct} + b)^2} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where:

t = temperature in centigrade.

a, b, and c = constants.

e = base of Napierian logarithms.

V = percentage of the optimum growth rate.

Also, a moisture ratio expressing humidity or aridity during a given period in a given location was developed by Thornthwaite as:

$$m = \frac{P - e}{e} = \frac{P}{e} - 1, \quad . \quad . \quad . \quad . \quad . \quad (5)$$

expressing the difference between precipitation and "potential evapotranspiration" divided by "potential evapotranspiration." In (4), optimum temperature for growth is at the point where numerator and denominator are equal. The second relationship, (5), approaches zero as water supply equals water need. Series of the growth index (4) are not available, thus making it nonoperational.

Up to this point nothing has been mentioned about interplant relationships. Beginning with a simple plant per unit area and increasing the density of the plant population from that point, it is obvious that over a considerable range of plant density, aggregate

¹Van't Hoff's law of physics expresses the velocity of a chemical reaction as an exponential function of temperature. Van't Hoff's law can be conceptualized as $A = n/V RT$, where: A = osmotic pressure. R = universal gas constant. T = absolute temperature. n = concentration of a solute in moles per liter.

emergence (also eventual production) is a linear function of the number of plants. As the number of plants on a fixed amount soil increases, the growth of each plant becomes more and more dependent upon the growth of other plants. This dependence is primarily competitive in the case of range grasses versus Pinyon-Juniper trees. Particularly critical is the competitive disadvantage the grasses have in obtaining moisture in dense stands of trees. Since a plant is unable to resist atmospherically induced pressures toward water loss, such losses will be incurred regardless of the occurrence of growth. The larger plant systems, therefore, can survive any periods of high "evapotranspiration" because of large storage capacity.

Because of this disadvantage, the introduction of range grasses (wheatgrasses, lovesgrasses, and sandrop, etc.) requires an interplant system providing a favorable competitive position for the grasses in the system. This suggests, as is being carried out, the artificial manipulation of the interplant system to tip the balance of nature toward a favorable environment for these range grasses.

Development of the variables. Above considerations suggest the critical variables in the emergence process of the range grasses. These variables, in order to be of use in a model of seedling establishment, must be measurable.

Water, the important nutrient, vehicle, and cooling agent, is measurable in the form of precipitation. Temperature, the underlying causal variable of the flow of water through the plant, is likewise measurable. The difficulty is their interrelationship when being used as single factors affecting seedling emergence.

Sunlight, a difficult factor to measure, is considered constant for two reasons. First, the emergence process takes place during the time the photosynthetic process is active. Second, transpiration is largely confined to the daylight hours because transpiration takes place on the undersurface of the leaves through specialized cells called stomata. These specialized cells are photo-sensitive, closing in the absence of sunlight.

Climatological theory suggests inverse relationship between precipitation and temperature. Oury (19) found a negative correlation of -.667 between these two variables. de Martonne (10) suggested a ratio of precipitation adding a constant to the denominator to avoid negative values:

$$I = \frac{P}{T + 10} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Ångström (3) later suggested a modification of the aridity index, which was proportional to precipitation amount and inversely proportional to an exponential function of temperature:

$$I = \frac{P}{1.07^t} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The agreement with physical theory is much closer and is specifically in agreement with Van't Hoff's law. The denominator doubles with each rise of 10 degrees centigrade in temperature. For empirical purposes it has the advantage of being continuous for negative values. Oury (20) found the Ångström aridity index to be particularly favorable for aggregation purposes, that is to handle crop production data gathered from a large region having a variation in rainfall patterns.

Manipulation of nature's balance to make the environment favorable for seedling emergence can be measured in three policy variables. Seeding projects first call for removal of the existing stand of Pinyon-Juniper trees. Success of this removal is measured by the percent of residual live trees to that of the total number of original trees on a tenth-acre plot (Part A, p.128). Second, the measure for plant numbers can be obtained by using the variable of seed rate on a per-acre basis for the seeding projects. Since moisture and its availability to plants via the soil is a critical factor influencing both germination and production, the third policy variable is the depth at which the seed is sown.

Another consideration is the timing in planting different grass species. It may be that no cover is required if the planting is done at a time when adequate amounts of moisture and optimum temperatures exist. The effect of timing is assumed to be taken care of in the aridity index (6) and (7), because only at particular times will there be a correspondence of critical values and emergence time of a particular species.

Seedling establishment, the dependent variable, can be measured in different ways such as plants per square foot, percent of the total seed planted which emerged, or by means of some qualitative measure such as "success" or "failure" in establishment. The latter measure presents the difficulties of a dichotomous dependent variable as well as subjective opinion about success or failure of a grass stand. The available data indicates that seeding establishment in the Pinyon-Juniper type is of this dichotomous nature. The records of the seeding projects only show the seeding to be classified as successful or failed.

The generalized model. The work of others illustrates the difficulties inherent in the formulation and interpretation of qualitative data. At the same time, their efforts show promise for the present study because a number of suitable analytic techniques have been developed for analogous situations (13, p.249).

Ordinarily, the dichotomous regression problem is treated as a regular linear regression problem, taking $E(Z)$ to be a linear function of the regressors, $Z = X'X\beta + \epsilon$, with $E(\epsilon) = 0$. Then classical least squares estimators are obtained. Two distinct difficulties arise. One, the assumption of homoskedasticity is untenable. For a particular set of x 's (a row of $X'X$), $\epsilon = Z_i - (X'X)_i\beta$. Since Z_i is either 0 or 1, ϵ_i must be either $-(X'X)^{-1}_i\beta$ or $1-(X'X)^{-1}_i\beta$. The distribution, if ϵ_i is to have zero expectations, is $f(\epsilon_t) = 1-(X'X)^{-1}_t\beta$ and $f(\epsilon_t) = (X'X)^{-1}_t\beta$ for $\epsilon_t = 1-(X'X)^{-1}_t\beta$ will variance, $E(\epsilon_t^2) = [(X'X)^{-1}_t\beta][1-(X'X)^{-1}_t\beta] = [E(Z_i)][1-E(Z_i)]$, since $E(Z_i) = (X'X)^{-1}_i\beta$ (13, p.249). Thus, the disturbance varies systematically with $E(Z_i)$ and hence with $(X'X)_i$. Second, the linear probability function allows inconsistency with the conditions required by the definition of $E(Z_i)$, that is, $0 \leq E(Z_i) \leq 1$, since a linear function is unbounded.

To avoid such difficulties, an alternative method to restrict the unbounded linear function and to explain the movement of the disturbance term must be found. A means is suggested by probit analysis employed by biometricians and modified by economists (13, p.250). Let C be an index which is a linear function of the regressors $(X_1 \dots X_n)_i$ and expressed as:

$$C_i = X'X\beta (8)$$

Let C^* be $\sim N(0,1)$ and determine Z by:

$$Z_i = \begin{cases} 1 & \text{if } C_i \geq C_i^* \\ 0 & \text{if } C_i < C_i^* \end{cases} (9)$$

Each Z_i is a function of the X_i 's, via the C_i , and of the C_i^* . The C_i^* 's play the role of disturbances, and they may be interpreted as critical values of C . The critical values, C_i^* , must stay within the 0,1 interval since this interval is determined by observed seeding establishment results.

Since C_i^* is $\sim N(0,1)$, let $F(Z_{io})$ equal the value of the standard normal cumulative distribution at Z_{io} , then:

$$\Pr \{Z = 1 | C\} = \Pr \{C^* \leq C | C\} = F(C) (10a)$$

$$\Pr \{Z = 0 | C\} = \Pr \{C^* > C | C\} = 1-F(C) (10b)$$

The probabilities via C_i are functions of the β_i 's and suggest use of maximum likelihood estimation of the β_i 's. If the sample is ordered such that the first R observations are those of establishment success and the remaining $S-R$ observations are of establishment failure, then the likelihood function of the sample is:

$$L = F(C_1) \cdots F(C_R) \cdot [1-F(C_{R+1})] \cdots [1-F(C_S)] (11a)$$

with logarithmic likelihood as:

$$L = \sum_{i=1}^R \ln F(C_i) + \sum_{i=R+1}^S \ln [1-F(C_i)] (11b)$$

Each term now is a function of the β_i 's and the standard normal cumulative distribution:

$$F(C_i) = \frac{1}{2\pi} \int_{-\infty}^{X'X\beta} e^{-\frac{u^2}{2}} du (11c)$$

Setting the derivatives with respect to the β 's equal to zero gives the nonlinear normal equations necessary to determine the maximum likelihood estimates.

In the probit method, conditional expectation is given as:

$$E(Z_i | C_i) = \text{Fr} \{ Z_i = 1 | C_i \} = F(C_i). \quad . \quad . \quad . \quad (12)$$

when the estimated expectation, $F(C_i)$, is:

$$Z_i = F(X'X\beta) \quad . \quad . \quad . \quad . \quad . \quad (13)$$

$F(C_i)$ has the same properties as that of the cumulative normal distribution, and thus falls in the unit interval.

Having solved for the β 's, the model expressing $\hat{C}_i$ as a function of the regressors and parameters is written as:

$$\hat{C}_i = \sum_{i=1}^4 \beta_i X_i, \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where:

$\hat{C}_i$ = the index following the probit model.

β_i = the estimated parameters.

X_1 = percent removal as tree competition.

X_2 = depth of seed cover.

X_3 = seeding rate per acre.

X_4 = Ångström aridity index for the critical period of establishment.

Given the $\hat{C}_i = F(X'X\beta)$, the probabilities of establishment (10a) and (10b) can be found by the cumulative normal distribution. The probabilities found measure seedling establishment in relative terms since no specific measure (plants per square foot, percent of total seed which germinated, etc.) is found in data so far collected from the pinyon-juniper type.

Empirical Applications - In this section the generalized model (14) is applied to four range improvement areas. Three of these areas are under the jurisdiction of the Bureau of Land Management and the other area includes projects under the jurisdiction of the Bureau of Indian Affairs at the Ft. Apache Indian Reservation and others under the jurisdiction of the Forest Service in the Sitgreaves National Forest. The areas were split in this manner because the weather patterns are differentiated and the management practices and grass species are different between regions.

The first area analyzed includes the fourth district in Colorado (Durango) combined with the sixth and ninth districts in Utah (Monticello).

In this region most of the improvement projects were aerial broadcast and seeded at a rate of 6-7 pounds, mainly of crested wheatgrass. For this reason the depth of cover and seeding rate variables were excluded since they are constant for all practical purposes.

Application of the model to the Monticello-Durango data yields:

$$\hat{C} = -1.47 + 2.57X_1 + .009X_4 - .01X_5, \quad . \quad . \quad . \quad (15)$$

where:

$\hat{C}$ = the index following the probit model.

X_1 = percent removal of tree competition.

X_4 = Ångström aridity index for the critical period of establishment.

$X_5 = X_1 X_2$.

The Ångström index measurement was taken for the period of time critical to seedling establishment adjusted for the time of planting. The ad-

justment was based on the observation of land managers regarding this critical moisture period and the time of planting. For example, discussions with most of the range managers of the three areas suggest that if the planting time is in middle to late October, the seeding has full advantage of March-June moisture the following spring. On the other hand, if planting is completed in May, the seeding only has the low moisture conditions of June and July to draw on during emergence in Colorado, Utah and Nevada. In Arizona and New Mexico the critical moisture period is August and September for the gramagrasses and lovegrasses. Crested wheatgrasses are not well adapted in these southern areas because they germinate in the spring and low moisture conditions exist at that time. In order to choose the critical period, correlations were run with seedling establishment on the Ångström aridity index corresponding to March-June, June-July, August-September, and September-October using Colorado, Utah, and Nevada data. The highest partial correlation of .737 corresponded to the March-June period. Then for the New Mexico and Arizona data, using the same periods with seedling establishment, the highest partial correlation coefficient of .694 corresponded with the August-September period. The empirical computation of the aridity index, using monthly mean temperatures and total precipitation data from Weather Bureau publications is:

$$I = \frac{P \times 12}{1.07^t}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

where temperature is converted to degrees centigrade (26). A program developed for the IBM 1620 digital computer was used for the computations. Some details of this program are found in this section's Appendix.

Multicollinearity occurred between the competition removal variable and the Ångström aridity index. This was expected in the Monticello-Durango area since low tree removal percentages were associated with low indexes producing failures. Thus, for the area, the interaction term, X_5 , was included in the model. Because of the multicollinearity, no interpretation of the affect of a single variable on the index following the probit model can be made. Thus the significance of the regression coefficients is a test on the coefficients jointly where the null hypothesis is $\beta_0 = \beta_1 = \beta_4 = \beta_5 = 0$, following the F-distribution. The calculated F of 98.26, using 2 and 21 degrees of freedom, gave evidence at the $\alpha = .01$ level that the regression coefficients were significantly different from zero. A coefficient of determination of .903 was obtained for the model. More informative is the computations of the conditional probabilities according to (10a) and (10b), as tabulated in Table 2.c.1.

Mean tree removal percentages of 74, 83, and 90 were obtained for the single chaining, dozing, and double chaining techniques respectively. From 2.c.1. it is seen that the higher tree removal percentages are generally associated with higher aridity indexes indicating better management practices with regards to planting time and providing a favorable competitive position for the new seeding.

The second area analyzed is that of the fifth district in Nevada and the fourth district in Utah and portions of the sixth and ninth districts in Utah. Hereafter this area will be referred to as the Cedar City-Caliente area. The establishment model was applied with all

Table 2.c.1. Probit model index and associated probabilities of seedling establishment for selected percentages of tree removal and Ångström aridity index for the Monticello-Durango area

Percentage tree removal	Critical period Ångström aridity index	Estimated probit index	Conditional probability
38	52	-.69	.2451
40	50	-.20	.4207
50	21	-.08	.4681
56	30	.09	.5359
50	71	.10	.5398
63	28	.26	.6026
65	72	.42	.6628
70	163	.74	.7704
77	131	.75	.7734
89	88	.82	.7939
80	282	.87	.8078
80	235	2.91	.9982
99	190	2.95	.9984
99	197	3.02	.9995

variables except seed rate per acre which was considered a constant for the area at 5-6 pounds. The estimated establishment equation was computed as:

$$\hat{C} = -.186 + .030X_1 + .703X_3 + .009X_4 - .006X_5, \quad (17)$$

where:

$\hat{C}$ and X_1 are as in (14) and

X_3 = depth of the seed cover.

X_4 = Ångström aridity index for the critical period of establishment, adjusted for time of planting.

$X_5 = X_2X_3$.

As was the case in (15), multicollinearity enters the model. In this case the multicollinearity is between depth of seed cover and the

aridity index, which is expected in this area since the practice of drilling the seed is associated with proper time of planting to take full advantage of spring moisture conditions. The joint test $\beta_0 = \beta_1 = \beta_3 = \beta_4 = \beta_5 = 0$ yielded a calculated F value of 188.46 using 2 and 21 degrees of freedom, which gives evidence that the coefficients, jointly, are significantly different from zero at the $\alpha = .01$. However, a look at the coefficient of the tree removal variable alone shows no significance. The data for percentage tree removal are grouped around high values of 99 percent, then 70 percent, and still lower at 59-60 percent. This is due to the management policy regarding the technique to be used in tree removal. The coefficient of determination for the model is .735. Table 2.c.2. shows the conditional probabilities for selected values of tree removal percent, depth of cover, and aridity index computed from (16).

From Table 2.c.2. it is apparent that the values indicate cover to be an important factor influencing seedling establishment and is particularly critical when moisture conditions are relatively low, i.e., an aridity index below 100. Even at low tree removal percentages, the probabilities still maintain values greater than 0.50 if a reasonable aridity index occurs and the seed is covered.

The third area analyzed is the combined Sitgreaves National Forest-Ft. Apache Indian Reservation area. This area has some projects which were seeded to crested wheatgrass, but most of the projects were seeded to the lovegrasses and gramagrasses more adapted to the area. Many of the control projects were merely pinyon-juniper tree removal projects to allow the native gramagrasses to recover to a

Table 2.c.2. Probit model index and associated probabilities of seeding establishment for selected percentages of tree removal, depth of seed cover, and Ångström aridity index for the Cedar City - Las Vegas area

Percentage tree removal	Depth of seed cover (inches)	Critical period Ångström aridity index	Estimated probit index	Conditional probability
28	0.00	2	.16	.4364
40	.20	23	.03	.5120
99	.20	9	.05	.5190
95	0.00	26	.08	.5319
59	0.00	41	.20	.5793
19	.20	52	.23	.5910
75	0.00	55	.33	.6293
99	.75	23	.47	.6808
99	1.00	61	.73	.7673
60	0.00	102	.75	.7734
99	.75	89	.77	.7794
80	1.50	197	.89	.8133
90	1.50	80	.90	.8159
70	.50	176	1.24	.8925

favorable competitive position without seeding. No significant cover of the seed was accomplished and for the most part the seed rate per acre is a constant at 6-7 pounds. The estimated model for the area is:

$$\hat{C} = -.982 + 1.387X_1 + .003X_2, \quad (18)$$

Where:

$\hat{C}$ is the same as in (15) and (17) and

X_1 = percent removed of tree competition.

X_2 = Ångström aridity index for the critical period of establishment adjusted for planting time.

The coefficient of determination for the model is .809, and the joint test on the regression coefficients yielded a calculated F-value

Table 2.c.3. Probit model index and associated probabilities for selected percentage of tree removal and Ångström aridity index for the Sitgreaves National Forest-Ft. Apache area

Percentage tree removal	Critical period Ångström aridity index	Estimated probit index	Conditional probability
45	68	-.15	.4404
60	28	-.06	.4761
55	67	-.02	.4920
55	82	.04	.5160
55	109	.12	.5478
95	70	.14	.5557
99	46	.53	.7019
95	109	.67	.7486
85	161	.70	.7580
95	133	.75	.7704
99	139	.82	.7939
90	190	.85	.8023
95	188	.92	.8212
99	334	1.43	.9236

of 35.942 using 2 and 17 degrees of freedom. A test was also made on the individual regression coefficients and the calculated F-values are 4.67, 19.88, and 23.95 for the null hypothesis $\beta_0 = 0$, $\beta_1 = 0$, and $\beta_2 = 0$ respectively, using 1 and 17 degrees of freedom. In all cases evidence supported the alternative hypothesis that the regression coefficients are significantly different from zero at the $\alpha = .01$ level. The conditional probabilities for selected values of tree removal percentage and aridity index are shown in Table 2.c.3.

The fourth area analyzed includes the 2nd, 3rd, and parts of the 10th and 5th districts in Utah. This is the Filmore-Murray area. The establishment model was applied with only kill and weather index variables:

$$\hat{C} = -.884 + 1.848X_1 + .010X_4 - .010X_3, \quad . \quad . \quad . \quad . \quad . \quad (19)$$

Where:

X_1 = kill percentage,

X_4 = critical period Ångström aridity index,

$X_5 = X_1 X_4$.

The historical reliance upon windrowing and drilling as a conversion method causes seed rate and depth to appear as virtual constants, so observations on these variables add nothing to the model. The interpretation of this result, however, is opposite that of the Monticello-Durango case. In that area broadcasting seed, without much cover, was always assumed, regardless of tree removal technique. In the present instance the seed is always assumed to be covered--which effectively limits the model's applicability to the single technique of windrowing.

Table 2.c.4. Probit model index and associated probabilities of seedling establishment for selected percentages of tree removal and Ångström aridity index for the Fillmore-Murray area.

Percentage tree removal	Critical period Ångström aridity index	Estimated probit index	Conditional probability
52	105	.58	.7190
70	94	.69	.7550
90	94	.72	.7640
32	159	.79	.7850
90	140	.93	.8104
90	149	.95	.8235
99	64	.95	.8285
99	140	.96	.8310
95	410	1.03	.8485
92	297	1.05	.8530
99	226	1.08	.8575
95	420	1.08	.8600

Of the areas studied, the Monticello-Durango area yielded the highest probability estimates but had the widest range of probabilities. For the most part the seed was not covered, but success in removing the pinyon-juniper trees was indicated by the data. Favorable spring moisture conditions exist as indicated by the aridity index in Table 2.c.1.

The Sitgreaves-Ft. Apache area has favorable late summer-fall moisture conditions. The seeding failures in this area were mainly due to planting cool season grasses requiring spring moisture conditions which are less favorable. This area was relatively successful in removing the pinyon-juniper trees.

The Cedar City-Caliente area has less favorable moisture conditions during the emergence time which explains why seed cover is important in the improvement method and is not independent of the aridity index. This area yielded low probability estimates due primarily to the fact that only a few of the projects had the seed drilled to provide cover.

The maximum probabilities are lowest of all for the Fillmore-Murray area, but on average they exceed those of the Cedar City-Caliente area. In the northern portion of the subject area the critical moisture period is narrowed by the fact that June and part of May is often dry. In practice this has been offset by greater reliance upon getting adequate seed cover, this causes the bunching of probabilities in a narrow 75-85 percent range.

For any practical application of the establishment models for the four areas where adequate and suitable data could be obtained, only

the probit tables are used. All the necessary computations have been made and are implicit in them. All that is necessary is to select the level of acceptable probability of establishment. This is associated with a range of kill percentages. These in turn imply certain techniques, and each of these ordinarily is associated with some method of seed application. In the Cedar City area the seed depth is indicated, and drilling may be necessary. The Fillmore-Murray probit assumes only drilling, so the probit table in this case indicates how good a windrowing job must be done.

Associated with the selected minimum acceptable probabilities and the associated kill levels are fairly definite values for the aridity indexes. These must be attained, that is, the weather during emergence needs to reach the tabulated value to satisfy the selected probability. If the required index levels are not likely to be achieved, site conversion must be delayed. The question is therefore, "What is the chance of the index being at the required value"? This is the next topic considered. All of the weather discussion that follows assumes that managers select 0.75 as the minimum conditional probability they will accept for establishment. Everything needed has been precomputed for this value. Choice of any other percentage requires a recomputation of all the Markov matrices which follow.

Weather in the Decision Process

Theoretical Process. Many theories have been advanced regarding weather patterns and much has been done to calculate normal weather conditions for given areas. "Normals" are valuable when taken into consideration in agricultural production decisions. In the case of the Pinyon-Juniper control decision, however, knowledge of weather movements from one state of condition to another is also needed. The costs of control and seeding are incurred in one season (fall), and the grass germinates and emerges in another season (spring).

It is generally conceded that spring moisture conditions are determined by the winter precipitation patterns. This relationship, however, does not help in the control decision since the removal of Pinyon-Juniper trees and planting must take place at an earlier time than winter in Colorado, Utah, and Nevada. Also in the Arizona and New Mexico Pinyon-Juniper areas, the late summer-early fall moisture patterns are quite different than the spring-early summer patterns because of the temperature patterns. In these areas the so called "Monsoon" moves in from Southwest to Northwest, the degree of which depends on the temperatures. As the moist air moves into the area, it is forced to rise by orographical lift and condenses as the warm air is cooled at higher elevations where the temperatures are cooler. The temperatures in the plateau areas of New Mexico and Arizona vary from year to year during the late summer-early fall season quite independently of the preceding season.

It is hypothesized, therefore, that the most appropriate decision tool is to obtain an estimate of the weather movement from a particular

weather state, i , in year $t-1$ to the same weather state, i , or different state, j , in year t . Land managers can obtain, in advance of control decision, the aridity index measure of the precipitation-temperature relationship and determine the weather conditions in year $t-1$ for a particular season such as the months March-June or August-September. From this movement scheme a control decision can be made based on the probability that state i moves to state i or j in a finite number of moves.

The Probability Model. The hypothesis suggested from the theoretical consideration is analogous to the basic assumption underlying a Markov chain. Any sequence of trials that can be subjected to probabilistic analysis is called a stochastic process. Thus for a stochastic process, it is assumed that movements of objects from one state to another are governed by a probabilistic mechanism. The finite Markov process is a finite stochastic process such that for any statement, q , whose value depends only on the outcomes before the n^{th} , the Markov property is expressed as:

$$\Pr \left\{ F_n = S_j \mid (F_{n-1}), q \right\} = \Pr \left\{ F_n = S_j \mid F_{n-1} = S_i \right\} \cdot \cdot \cdot \quad (20)$$

where:

F_n = a sequence of outcome functions, $n = 0, 1, 2, \dots$

S_i = state i .

S_j = state j .

Assuming $F_{n-1} = S_i$ and q are consistent and that the outcome of the last experiment is known, then the n^{th} step transition probabilities, denoted as $P_{ij}(n)$ are:

$$P_{ij}(n) = \Pr(S_j \mid S_i) \cdot \cdot \cdot \cdot \cdot \cdot \quad (21)$$

The transition matrix for a Markov chain is the matrix P whose elements consist of P_{ij} . Then given probability, $P_{(o)j}$, that the process starts in S_i , the initial probability vector π_0 , representing the probabilities of the starting states, may be formulated. This vector together with P determines the chain process.

For the present purposes the observed movement of the Ångström aridity index from state i of year $t-1$, to state j of year t , can best be described as an ergodic chain consisting in its entirety of a single ergodic set. An ergodic chain is a Markov chain such that it is possible to go from any state to any other state with period 1 and all sufficiently high powers of P positive. The transition probabilities are estimated using the method derived by Anderson and Goodman (1957) as:

$$\hat{P}_{ij} = \frac{n_{ij}}{\sum_j n_{ij}} , \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

where:

P_{ij} = the probability of moving from state i to j .

n_{ij} = the number of moves from state i to j .

The limiting matrix, A , is found by computing $\lim_{n \rightarrow \infty} P^n = A$ and is such that each row is the same probability vector, W . The limiting vector, W , indicates the long-run probabilities associated with S_i . The mean recurrence time for any starting state will be the column vector $\frac{1}{W}$.

The fundamental matrix, Z , is derived by:

$$Z = (I - P + A)^{-1} . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

Since $I - Z = A = FZ$, the mean first passage matrix, M , can be found as:

$$M = (I - Z + ADZ_{dg}) D, \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

where:

D = the reciprocal of the diagonal of A .

Z_{dg} = the diagonal of Z .

For a given control technique a certain magnitude of the aridity index is necessary to estimate a favorable probability of seedling establishment from the probit model (14). Thus the initial states producing the Markov chain are defined by choosing a desired probability of establishment, then each state is defined as the interval of aridity index magnitude which gives that probability or greater given each different control technique.

Application of the Model: Monticello-Durango. The establishment model (15) for the Monticello-Durango area is employed to decide the intervals of aridity index magnitude, giving a probability of 0.75 for seedling establishment. Four tree removal techniques are generally used in the Pinyon-Juniper woodlands. These are single chaining, cabling, bulldozing, and double chaining. The mean percent tree removal is 74 percent for single chaining. The cabling technique is considered the same as single chaining, with respect to mean tree removal percent, in the areas of Colorado, Utah, and Nevada. The mean tree removal percent is 82 percent for bulldozing and 90 percent for double chaining. Also considered is the worst experience for the area with only 38 percent of the trees removed. Substituting these values into (15) and solving for the Ångström aridity index, which produces a .75 probability or greater defines three states for the aridity index I , for the given techniques as:

1. $S_1 = I \geq 203$, for the lowest tree removal experience.

2. $S_2 = 110 \leq I < 203$, for the single chaining technique.

3. $S_3 = 13 \leq I < 110$, for the bulldozing technique.

When the double chaining technique is used, the value of the aridity index required is negative. The lowest March-June grouped aridity index for the area was at zero, therefore, only three states are defined.

Precipitation and temperature data to compute the Ångström aridity index are taken for five weather stations in the area: Cortez and Northdale, Colorado; Blanding, LaSal, and Monticello, Utah. A Markov chain then was developed for each using the three initial states previously described. Then each of the transition matrices is computed by the method of maximum likelihood. A computer program, developed for the IBM 1620 digital computer, is used to compute the limiting matrix from the transition matrix. Details of this program are found in Appendix B.

The transition matrix, P, for Monticello is:

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .6000000 & .2666667 & .1333333 \\ .4545455 & .3636364 & .1818181 \\ .2500000 & .5000000 & .2500000 \end{bmatrix} \end{matrix} \quad (25)$$

The transition matrix indicates that relatively favorable moisture conditions exist in the spring for seeding projects near Monticello, Utah. In fact, an aridity index of 203 or greater is not a rare occurrence. The probability of moving from an aridity index of 203 or greater in the spring of year $t-1$ to the same state in the spring of year t is .60. The probability of moving from state 3, the state requiring the lowest aridity index, to state 1 is .25. There is a greater probability, .45,

of moving from state 2 to state 1. If weather conditions are such that the aridity index is in state 3, half of the time the index will be in state 2 the next year. From state 2 the aridity index will be in state 1 the next year for nearly half of the time. This is not to infer that the index moves from state 3 to state 2, and then to state 1 in that order. The first order Markov chain only infers the probability of transition from i to j without consideration of how the system arrived in i.

The transition matrix for Northdale is computed as:

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .7058820 & .1764710 & .1176470 \\ .2222222 & .3333333 & .4444445 \\ .5714290 & .1428570 & .285714 \end{bmatrix} \end{matrix} \quad . \quad . \quad . \quad (26)$$

indicating favorable March-June moisture conditions for projects near this station. A probability of approximately .71 of moving from an aridity index of 203 or greater to the same state is the highest for the weather stations of the Monticello-Durango area. There exists an approximate .57 probability of moving from an index between -13 and 109 to an index of 203 or greater.

At Blanding the moisture conditions for March-June are considerably less favorable. The transition matrix for Blanding is:

$$\begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .2000000 & .0000000 & .8000000 \\ .2000000 & .2000000 & .6000000 \\ .1250000 & .2083333 & .6666667 \end{bmatrix} \end{matrix} \quad . \quad . \quad . \quad (27)$$

The highest transition probability is approximately .80 of being in state 3 after having been in state 1 initially. Low probabilities of movement from both state 2 and state 3 to state 1 indicate a pattern of low aridity indexes.

The Cortez transition matrix indicates a transition probability of approximately .55 of recurrence in state 3. The transition matrix is computed as:

$$\begin{matrix}
 & & S_1 & S_2 & S_3 \\
 P = \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .1818181 & .5454540 & .2727273 \\ .4766666 & .4166666 & .1666667 \\ .3636364 & .0909090 & .5454546 \end{bmatrix} & . & . & (28)
 \end{matrix}$$

Moisture conditions at LaSal are comparable to those of Cortez as indicated by the transition matrix:

$$\begin{matrix}
 & & S_1 & S_2 & S_3 \\
 P = \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .3846150 & .3846150 & .2307700 \\ .625000 & .125000 & .250000 \\ .4166667 & .0833333 & .5000000 \end{bmatrix} & . & . & (29)
 \end{matrix}$$

(with the exception of the even distribution of probabilities of moving from state 1 to state 2 and the favorable probability of moving to state 1 given after the initial state 2 has occurred.) As the projects move from the Monticello and Northdale vicinity north to the more desert-like LaSal vicinity and south and southeast to Blanding and Cortez, tree removal becomes more important because the odds for favorable spring moisture conditions are less.

The asymptotic behavior of the Markov chains indicates compliance with the assumptions that the system of aridity index movement is a

first order Markov chain. The limiting matrix, A, for the Monticello weather station, computed by $\lim_{n \rightarrow \infty} P^n$, is:

$$A = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_3 \\ S_2 \\ S_1 \end{matrix} & \begin{bmatrix} .4913298 & .3391136 & .1695565 \\ .4913298 & .3391136 & .1695565 \\ .4913298 & .3391136 & .1695565 \end{bmatrix} \end{matrix} \quad . \quad . \quad (30)$$

with limiting vector, $W = [.4913298, .3391136, .1695565]$. Raising the transition matrix (24) to successive powers up to P^{10} , and comparing with the limiting matrix A, indicates relatively fast convergence as:

$$P^{10} = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .4913297 & .3391134 & .1695564 \\ .4913296 & .3391135 & .1695564 \\ .4913294 & .3391137 & .1695565 \end{bmatrix} \end{matrix} \quad . \quad . \quad (31)$$

The limiting vector, W, reveals the long run probability of each state occurring. These probabilities are approximately .49, .34, and .17 for state 1, state 2, and state 3 respectively. The probability of an aridity index of 203 or greater occurring is nearly one-half.

The limiting matrix for Northdale also has the asymptotic properties, complying with the first order assumptions. The limiting matrix is:

$$A = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .5792920 & .2005244 & .2201835 \\ .5792920 & .2005244 & .2201835 \\ .5792920 & .2005244 & .2201835 \end{bmatrix} \end{matrix} \quad . \quad . \quad (32)$$

with limiting vector, $W = [.5792920, .2005244, .2201835]$. Comparison of the transition matrix, P, raised to P^{10} as:

$$P^{10} = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .5792919 & .2005242 & .2201834 \\ .5792919 & .2005243 & .2201833 \\ .5792918 & .2005242 & .2201835 \end{bmatrix} \end{matrix} \quad . \quad . \quad (33)$$

with $\lim_{n \rightarrow \infty} P^n$ (29) indicates rapid convergence. The long-run probabilities of each state are approximately .58, .20, and .22 for states 1, 2, and 3 respectively. Of the five stations studied in the Monticello-Durango area, Northdale has the highest long-run probability for state 1.

The Blanding weather situation as described by the Markov scheme is opposite that of either Monticello or Northdale. The limiting matrix is:

$$A = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .149343 & .175698 & .674685 \\ .149343 & .175698 & .674685 \\ .149343 & .175698 & .674685 \end{bmatrix} \end{matrix} \quad . \quad . \quad (34)$$

with, $W = [.149343, .175698, .674685]$, indicating a .67 probability of obtaining an aridity index between -13 and 110. The asymptotic behavior of the transition matrix (27) indicates convergence at a higher power, P^{15} , which is comparable to the limiting matrix (34) as:

$$P^{15} = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .1493848 & .1757465 & .6748684 \\ .1493849 & .1757466 & .6748683 \\ .1493847 & .1757468 & .6748684 \end{bmatrix} \end{matrix} \quad . \quad . \quad (35)$$

The limiting matrix for LaSal is:

$$\begin{array}{c}
S_1 \quad S_2 \quad S_3 \\
A = \begin{array}{c} S_1 \\ S_2 \\ S_3 \end{array} \begin{bmatrix} .4498269 & .2283733 & .3217997 \\ .4498269 & .2283733 & .3217997 \\ .4498269 & .2283733 & .3217997 \end{bmatrix} \quad . \quad (36)
\end{array}$$

and the limiting vector, $W = [.4498269, .2293733, .3217997]$, indicating similar probabilities to those of Monticello. Cortez has an even distribution of long run probabilities between the three states as revealed by the limiting matrix:

$$\begin{array}{c}
S_1 \quad S_2 \quad S_3 \\
A = \begin{array}{c} S_1 \\ S_2 \\ S_3 \end{array} \begin{bmatrix} .3235294 & .3529409 & .3235296 \\ .3235294 & .3529409 & .3235296 \\ .3525294 & .3529409 & .3529409 \end{bmatrix} \quad . \quad (37)
\end{array}$$

and limiting vector, $W = [.3235294, .3529409, .3235296]$.

The mean first passage time, an important tool to determine the timing for seeding projects to be initiated, is next computed from the transition matrix, fundamental matrix, and the limiting matrix. The fundamental matrix has important use in computation of the mean first passage time, as well as other uses which will be seen later. The fundamental matrix, Z , is derived by $Z = (I - P - A)^{-1}$ from (23) and is shown only for the Monticello weather station at this point as:

$$\begin{array}{c}
S_1 \quad S_2 \quad S_3 \\
Z = \begin{array}{c} S_1 \\ S_2 \\ S_3 \end{array} \begin{bmatrix} 1.1367487 & .0920116 & -.0460060 \\ .0920116 & 1.0298757 & -.0155732 \\ -.3065058 & -.2043355 & 1.1008981 \end{bmatrix} \quad . \quad (38)
\end{array}$$

Z has similar properties as that of P , the transition matrix, but does not

necessarily have all non-negative entries.

The fundamental matrix (38) is employed in the derivation of the mean first passage matrix, M, for Monticello as:

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} 2.0352927 & 2.7656340 & 6.7641412 \\ 2.0352927 & 2.9488643 & 6.5846564 \\ 2.6352927 & 3.6345213 & 5.8977391 \end{bmatrix} \end{matrix} . \quad (39)$$

Where the main diagonal is the same as $D = \frac{1}{W}$, the mean recurrence time for each state. The recurrence of states 1 and 2, implying an aridity index above 110 is frequent, giving corroborative evidence of the favorable spring moisture patterns of this vicinity. Also, the mean first passage time for either states 1 or 2 is relatively frequent. Thus, if a particular year were marked by failure in terms of the aridity index, the mean time to pass for the first time from state 3 to state 1 is approximately two and one-half years.

For Northdale the pattern is similar to that of Monticello, for the recurrence time of state 1. The mean first passage time matrix:

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} 1.7262451 & 5.7728724 & 5.3825580 \\ 4.0467813 & 4.9869242 & 3.4863684 \\ 1.9941340 & 6.0061238 & 4.5416663 \end{bmatrix} \end{matrix} . \quad (40)$$

indicates less frequent passage of time from state 2 to state 1, and more frequent entry from state 2 to state 3. However, regardless of the initial entrance of the aridity index in state 3, a frequent move from state 3 to 1 is indicated by (40).

Blanding, as previously indicated by (27) and (34) has moisture patterns opposite of Monticello and Northdale. Planning the time of Pinyon-Juniper control and seeding becomes crucial in this vicinity as indicated by the mean first passage matrix:

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} 6.6959950 & 4.8508630 & 1.3552840 \\ 7.4699041 & 5.6915840 & 1.6512640 \\ 7.2766110 & 5.6959386 & 1.4821730 \end{bmatrix} \end{matrix} \quad . \quad . \quad (41)$$

where the mean recurrence time of state 1 is approximately seven years as opposed to one and one-half years for state 3. The mean first passage time matrices:

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} 2.2230773 & 3.4545531 & 4.2257975 \\ 3.5454590 & 4.3787955 & 4.1612840 \\ 2.2999991 & 4.8787957 & 3.1075230 \end{bmatrix} \end{matrix} \quad . \quad . \quad (42)$$

and:

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} 3.0909092 & 2.6666707 & 4.5151187 \\ 3.2968423 & 2.8333355 & 4.2970070 \\ 4.1513525 & 4.9221931 & 3.0909072 \end{bmatrix} \end{matrix} \quad . \quad . \quad (43)$$

for the LaSal and Cortez stations respectively. LaSal is similar to Monticello and Cortez shows approximately equal mean first passage times for the movement i to j .

Three years may seem to be a relatively frequent passage time from state 3 to state 1. However, in terms of moisture demanded by the

seedling emergence process, three years of unfavorable moisture conditions insures failure, as the young seedlings cannot survive that long before they become desiccated.

The fundamental matrix is also of importance in deriving the limiting variance for the number of times in a state in the first n steps. Also an important use is made of the Central Limit Theorem for Markov chains, the proof of which can be found in Feller (1957, pp. 271-272). In essence the theorem states that for an ergodic chain, let $Y^{(n)}_j$ be the number of times in states s_j in the first n steps, and let $W = [W_j]$ and $V = [V_j]$ be respectively the steady state vector and limiting variance vector, than if $V_j = 0$, for any numbers $r < S$:

$$\Pr \left[r \leq \frac{Y^{(n)}_j - nW_j}{\sqrt{nV_j}} < S \right] \sim \frac{1}{\sqrt{2\pi}} \int_r^S e^{-\frac{U^2}{2}} dx \quad . \quad . \quad (44)$$

as $n \rightarrow \infty$ for any starting state. The theorem says that, for large n, $\frac{Y^{(n)}_j - nW_j}{\sqrt{nV_j}}$ would have approximately a normal distribution. The limiting variance is derived by:

$$V_j = \left\{ W_j (2Z_{jj} - 1 - W_j) \right\} \quad . \quad . \quad . \quad . \quad . \quad (45)$$

where the Z_{jj} are the main diagonal elements of the fundamental matrix and V_j, W_j are as defined previously.

The limiting variance vectors for the Monticello, Northdale, Blanding, LaSal and Cortex weather stations respectively are:

$$V = [.384, .244, .175], \quad . \quad . \quad . \quad . \quad . \quad (46)$$

$$V = [.413, .107, .195], \quad . \quad . \quad . \quad . \quad . \quad (47)$$

$$V = [.146, .159, .259], \quad . \quad . \quad . \quad . \quad . \quad (48)$$

$$V = [.182, .207, .375], \quad . \quad . \quad . \quad . \quad . \quad (49)$$

and,

$$V = [.147, 308, 452] \quad . \quad . \quad . \quad . \quad . \quad (50)$$

Thus, for example, using the Monticello limiting variance vector, the Central Limit Theorem says that $\frac{Y^{(n)} - nW_1}{\sqrt{.384}}$ would, for large n , have

a normal distribution. The estimated number of years in 100 years having an aridity index of 203 or greater would be unlikely to deviate from .38 by more than 11 (probably about .077). Though the limiting variance is relatively large, it can be said that approximately one-third of the time the spring aridity index will have a value of 203 or greater.

Application of the Model: Cedar City-Caliente. The establishment model (17) for this area introduces two policy variables to be taken care of in the decision model. The depth of seed cover, the additional policy variable, is set at two values: .88 inches for drilling the seed and zero for no cover. This defines two systems in terms of the aridity index required to generate a .75 or greater probability of establishment given the techniques of tree removal.

The states are again defined for the worst tree removal experience, single chaining, bulldozing, and double chaining. The mean success in tree removal for these techniques are respectively, 19 percent, 74 percent, 83 percent, and 90 percent. The first system is derived by holding depth of seed cover at zero. Substituting the values for tree removal and seed cover into (17) are solving for the value of the aridity index, I , required to generate .75 probability or greater, the states are defined as:

1. $S_1 = I \geq 96$, for the worst tree removal experience.

2. $S_2 = 94 \leq I < 96$, for single chaining.
3. $S_3 = 90 \leq I < 94$, for bulldozing and double chaining.
4. $S_4 = I < 90$.

States 3 and 4 vary from the previous definitions of the initial states. There is little differentiation of the aridity index magnitude required by either substituting 83 percent or 94 percent in (17). Hence, the bulldozing and double chaining technique are combined in state 3. State 4 allows a measure of the probability of occurrence of an index less than 90, since the data does have values in this range.

Precipitation and temperature data to compute the aridity index are used for four weather stations: Modena and Wah Wah Ranch, Utah; Caliente and Pioche, Nevada. Using the method of maximum likelihood, the transition matrices for the Modena, Wah Wah, Caliente, and Pioche weather stations are respectively:

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} .6476590 & .0000000 & .0588230 & .294118 \\ 1.0000000 & .0000000 & .0000000 & .0000000 \\ 1.0000000 & .0000000 & .0000000 & .0000000 \\ .5000000 & .2000000 & .0000000 & .3000000 \end{bmatrix} \end{matrix} \quad (51)$$

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} .5000000 & .0000000 & .0000000 & .5000000 \\ 1.0000000 & .0000000 & .0000000 & .0000000 \\ 1.0000000 & .0000000 & .0000000 & .0000000 \\ .5000002 & .1666666 & .1666666 & .1666666 \end{bmatrix} \end{matrix} \quad (52)$$

$$\begin{array}{c}
 S_1 \\
 P = S_2 \\
 S_3 \\
 S_4
 \end{array}
 \begin{array}{c}
 S_1 \\
 S_2 \\
 S_3 \\
 S_4
 \end{array}
 \begin{bmatrix}
 .4285710 & .0000000 & .0000000 & .5714290 \\
 .5000000 & .5000000 & .0000000 & .0000000 \\
 1.0000000 & .0000000 & .0000000 & .0000000 \\
 .4285710 & .0000000 & .1428580 & .4285710
 \end{bmatrix}
 \quad (53)$$

and,

$$\begin{array}{c}
 S_1 \\
 P = S_2 \\
 S_3 \\
 S_4
 \end{array}
 \begin{array}{c}
 S_1 \\
 S_2 \\
 S_3 \\
 S_4
 \end{array}
 \begin{bmatrix}
 .8181820 & .0000000 & .0909090 & .0909090 \\
 1.0000000 & .0000000 & .0000000 & .0000000 \\
 .5000000 & .5000000 & .0000000 & .0000000 \\
 .5000000 & .0000000 & .0000000 & .5000000
 \end{bmatrix}
 \quad (54)$$

The Pioche (54) and Modena (51) transition matrices reveal high probabilities of moving from the initial state 1 to state 1 in the next move. Because of the small difference in the values of the aridity index between states 1, 2, and 3, the important inference from all the transition matrices is the probabilities of movement from state 4 to state 1. This movement is from a low aridity index, given a successful tree removal, to a high index, given that little success in tree removal is realized. In both cases it is assumed that nothing is done to cover the seed. The Wah Wah matrix (52) reveals a probability of .50 for moving from state 4 to state 1, with the lowest probability of recurrence of state 4. Pioche, the station having the highest probability of recurrence of state 1, has 50 percent chance of moving to state 1 from state 4, and the same probability of recurrence of state 3. Confidence cannot be placed in the probabilities of movement from state 2 and 3 in

any of the matrices because of the lack of real differentiation between states in terms of the aridity index.

The limiting matrices for Modena, Wah Wah, Caliente, and Pioche are respectively:

		S_1	S_2	S_3	S_4		
S_1	A =	$\begin{bmatrix} .6397850 & .0537634 & .0376340 & .2688174 \\ .6397850 & .0537634 & .0376340 & .2688174 \\ .6397850 & .0537634 & .0376340 & .7688174 \\ .6397850 & .0537634 & .0376340 & .7688174 \end{bmatrix}$					
S_2							
S_3							
S_4							

.

.

(55)

		S_1	S_2	S_3	S_4		
S_1	A =	$\begin{bmatrix} .5555561 & .0555553 & .0555553 & .3333333 \\ .5555561 & .0555553 & .0555553 & .3333333 \\ .5555561 & .0555553 & .0555553 & .3333333 \\ .5555561 & .0555553 & .0555553 & .3333333 \end{bmatrix}$					
S_2							
S_3							
S_4							

.

.

(56)

		S_1	S_2	S_3	S_4		
S_1	A =	$\begin{bmatrix} .4666665 & .0000000 & .0666670 & .4666664 \\ .4666665 & .0000000 & .0666670 & .4666664 \\ .4666665 & .0000000 & .6666670 & .4666664 \\ .4666665 & .0000000 & .6666670 & .4666664 \end{bmatrix}$					
S_2							
S_3							
S_4							

.

.

(57)

and,

		S_1	S_2	S_3	S_4		
S_1	A =	$\begin{bmatrix} .7586209 & .0344827 & .0689654 & .1379309 \\ .7586209 & .0344827 & .0689654 & .1379309 \\ .7586209 & .0344827 & .0689654 & .1379309 \\ .7586209 & .0344827 & .0689654 & .1379309 \end{bmatrix}$					
S_2							
S_3							
S_4							

.

.

(58)

The row vector W , which is any row of the limiting matrix A , has as entries the long-run probabilities for each state. The limiting matrix (58) indicates more favorable spring moisture conditions for the Pioche vicinity than the other weather stations. Also, the lowest probability of state 4 occurring is revealed by the Pioche matrix. Each transition matrix converged at P^{15} , which is comparable to $\lim_{n \rightarrow \infty} P^n$.

The mean first passage times for Modena, Wah Wah, and Pioche are respectively:

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} 1.5670250 & 17.5549016 & 21.8524445 & 3.6349796 \\ .9500761 & 18.6001410 & 26.5562231 & 4.6409577 \\ .9965551 & 18.5738327 & 26.5717170 & 4.6446974 \\ 1.7266861 & 13.4387871 & 28.5865360 & 3.7199972 \end{bmatrix} \end{matrix} \quad (59)$$

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} 1.7999980 & 18.9474362 & 18.9474344 & 8.5263075 \\ 13.9262998 & 18.0000828 & 18.0000846 & 8.5263075 \\ 13.2603006 & 18.0000846 & 18.0000838 & 1.4210662 \\ 20.0841521 & 12.3158727 & 12.3158709 & 3.0000003 \end{bmatrix} \end{matrix} \quad (60)$$

and,

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} 1.3181814 & 26.9520832 & 11.9247463 & 19.7823234 \\ 3.9384153 & 29.0000493 & 14.1929373 & 16.1965961 \\ 2.9685076 & 16.0841088 & 14.5000246 & 15.3483047 \\ .9405156 & 23.3508542 & 9.8693895 & 7.2500070 \end{bmatrix} \end{matrix} \quad (61)$$

Since no long-run probability is defined for state 2 in (53), the Caliente matrix of mean first passage times reduces to the mean recurrence, time for

states 1 and 4 and the mean first passage times, from state 4 to state 1 and state 1 to state 4. These are respectively: 2.1428579, 2.1428583, 2.6522463, and 2.3207018.

The limiting variance vectors for Modena, Wah Wah, and Pioche are respectively:

$$V = [.219, .040, .036, 1.091], \quad . \quad . \quad . \quad . \quad (62)$$

$$V = [12.820, .032, .052, 1.331], \quad . \quad . \quad . \quad . \quad (63)$$

and,

$$V = [12.820, .030, .044, .578]. \quad . \quad . \quad . \quad . \quad (64)$$

The limiting variance for states 1 and 4 for Caliente are .684 and .326 respectively. No limiting variance is derived from the other two states since w_{22} is not defined in (57). Frequent passage time from state 4 to state 1 is indicated by (59) and 61). The mean recurrence time for state 1 in (60) is frequent, but from any other state a lapse of time as high as 13, 14, or 20 years is required before entry into state. Because of the small differentiation between states, the Caliente data does not coincide with the Markov scheme when the asymptotic properties are considered.

The introduction of the seed cover variable prescribes a different Markov chain, and new initial states are defined. As is expected, when seed cover is substituted into the establishment model (17), a lower value of an aridity index is required to generate a .75 probability of establishment.

In fact the value of the aridity index required, if only 19 percent tree removal, is realized and the seed is covered at .88 inches, is 65 or greater. In the previous scheme the value had to be 96 or greater for a

19 percent tree removal. A seed cover of .88 inches in depth is used, since this value is the mean for the seed drilling technique of the Ceda City-Caliente area. The new states are defined in terms of the aridity index, I, for the given tree removal techniques at the seed cover level of .88 inches as:

1. $S_1 = I \geq 65$, for the worst experience with tree removal.
2. $S_2 = 60 \leq I < 65$, for bulldozing and single chaining.
3. $S_3 = I < 60$, for double chaining.

Again small differentiation between states is present, and the only real inference that can be made is the probability of movement from the third state to the first state.

The transition matrices for Modena, Wah Wah, Caliente, and Pioche, using the new initial states, are respectively:

$$\begin{array}{c}
 \begin{array}{c} S_1 \\ S_2 \\ S_3 \end{array} P = \begin{array}{c} S_1 \\ S_2 \\ S_3 \end{array} \begin{bmatrix} .7037028 & .0370370 & .2592592 \\ 1.0000000 & .0000000 & .0000000 \\ .8750000 & .1250000 & .0000000 \end{bmatrix} \begin{array}{c} . \\ . \\ . \end{array} \quad (65)
 \end{array}$$

$$\begin{array}{c}
 \begin{array}{c} S_1 \\ S_2 \\ S_3 \end{array} P = \begin{array}{c} S_1 \\ S_2 \\ S_3 \end{array} \begin{bmatrix} .6250000 & .1250000 & .2500000 \\ .5000000 & .0000000 & .5000000 \\ 1.0000000 & .0000000 & .0000000 \end{bmatrix} \begin{array}{c} . \\ . \\ . \end{array} \quad (66)
 \end{array}$$

$$\begin{array}{c}
 \begin{array}{c} S_1 \\ S_2 \\ S_3 \end{array} P = \begin{array}{c} S_1 \\ S_2 \\ S_3 \end{array} \begin{bmatrix} .6250000 & .1250000 & .2500000 \\ 1.0000000 & .0000000 & .0000000 \\ .4000000 & .0000000 & .6000000 \end{bmatrix} \begin{array}{c} . \\ . \\ . \end{array} \quad (67)
 \end{array}$$

and,

$$\begin{matrix}
 & S_1 & S_2 & S_3 \\
 \begin{matrix} S_1 \\ P = S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .8125000 & .1250000 & .0625000 \\ .6666667 & .3333333 & .0000000 \\ .5000000 & .0000000 & .5000000 \end{bmatrix} & . & . & .
 \end{matrix} \tag{68}$$

Generally these transition matrices indicate higher probabilities of moving from the lowest state in terms of the aridity index to the highest state on the next step than do (51), (52), (53), and (54). In (65) and (66), the probability of recurrence of the lowest state is reduced to zero but is increased in (67). Since spring moisture conditions are considerably more favorable in the vicinity of Pioche compared to the other station, the affect of cover on the probabilities generated is less. Only the transition matrices are presented since the asymptotic properties follow proportional to the changes in the transition matrices induced by the introduction of seed cover.

Application of the Model: Sitgreaves-Ft. Apache. In the Sitgreaves National Forest-Ft. Apache Indian Reservation area the only policy variable of significance in the establishment model is tree removal. The aridity index used in the model is the grouped index for August-September. Substituting the various values for percent tree removal in (18) and solving for the aridity index, I, generating a .75 probability of establishment, the following states are defined:

1. $S_1 = I \geq 346$, for the worst tree removal experience of 45 percent.
2. $S_2 = 263 \leq I < 346$, for the cabling technique at a mean percent of 63.
3. $S_3 = 212 \leq I < 263$, for the single chaining technique at a mean

percent of 74.

4. $S_4 = 170 \leq I < 212$, for the bulldozing technique at a mean percent of 83.

5. $S_5 = 137 \leq I < 170$, for the double chaining technique at a mean percent of 90.

6. $S_6 = I < 137$, which covers the remaining computed aridity indexes.

Precipitation and temperature data from Cibecue, Pinedale, and Show Low, Arizona is used to compute the aridity indexes. The transition matrices using the indexes for Cibecue, Pinedale, and Show Low are respectively:

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{matrix} & \begin{bmatrix} .3750000 & .0000000 & .0000000 & .3650000 & .1250000 & .1350000 \\ .0000000 & .0000000 & .0000000 & .3333333 & .3333333 & .3333334 \\ .0000000 & .1666667 & .3333333 & .1666667 & .0000000 & .3333333 \\ .0000000 & .0000000 & .0000000 & .0000000 & .3333333 & .6666667 \\ .0000000 & .0000000 & .2500000 & .0000000 & .2500000 & .5000000 \\ .357142 & .0000000 & .0714280 & .2142850 & .0000000 & .2857150 \end{bmatrix} \end{matrix} \quad (69)$$

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{matrix} & \begin{bmatrix} .2000000 & .2000000 & .2000000 & .0000000 & .2000000 & .2000000 \\ .2500000 & .0000000 & .0000000 & .2500000 & .2500000 & .2500000 \\ .2000000 & .2000000 & .2000000 & .0000000 & .2000000 & .2000000 \\ .0000000 & .0000000 & .0000000 & .2500000 & .2500000 & .5000000 \\ .0000000 & .2500000 & .2500000 & .2500000 & .2500000 & .0000000 \\ .6000000 & .2000000 & .2000000 & .0000000 & .0000000 & .0000000 \end{bmatrix} \end{matrix} \quad (70)$$

and,

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{matrix} & \begin{bmatrix} .0000000 & .0000000 & .0000000 & .5000000 & .5000000 & .0000000 \\ .0000000 & .0000000 & .0000000 & .0000000 & .0000000 & 1.0000000 \\ .5000000 & .0000000 & .0000000 & .0000000 & .5000000 & .0000000 \\ .0000000 & .0000000 & .0000000 & .0000000 & .0000000 & 1.0000000 \\ .1111111 & .0000000 & .1111111 & .1111111 & .1111111 & .5555556 \\ .0000000 & .1111111 & .1111111 & .2222222 & .4444445 & .1111111 \end{bmatrix} \end{matrix} \quad (71)$$

The Cibecus matrix (69) indicates approximately .38 probability of recurrence of state 1. The Pinedale matrix indicates a .60 probability of moving from an index of below 137 to one of over 346. Both (70) and (71) indicate no probability of recurrence of state 1. The high index of 346 is rarely obtainable except in Pinedale, indicating that a 45 percent tree removal is a sure gamble with establishment failure. Actually, the higher probabilities generally occur in the movements from states 4 and 5 to state 6, indicating the most frequent aridity index of some value less than 170. This suggests that the bulldozing and double chaining techniques should be the tree removal techniques used if the seed is not covered.

A further look at the asymptotic properties of this particular Markov scheme reveals the same outlook for projects in the vicinity of the three weather stations. The limiting vectors, w , taken from a row of the limiting matrix A , reveal the long-run probabilities of each state for Cibecue, Pinedale, and Show Low as:

$$W = [.2833934, .0136785, .0820712, .1067980, .1007773, .4132813], \quad (72)$$

$$= [.1753020, .1480327, .1480327, .1589404, .1885469, .1811453], \quad (73)$$

and,

$$W = [.0523077, .0461537, .0753845, .1476922, .2630771, .4153846]. \quad (74)$$

In (73), the probabilities are somewhat evenly distributed among the states. State 6 in (72) and (74) has the greatest probability of occurring. State 1 has low probability for all vectors.

The mean first passage times matrices indicate less frequent mean recurrence times and passage times for these Arizona weather stations than is indicated for the Colorado, Utah, and Arizona stations previously discussed. The mean first passage times matrices for Cibecue, Pinedale, and Show Low are respectively:

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{matrix} & \begin{bmatrix} 3.5286636 & 64.3736593 & 4.8299964 & .0916449 & 10.0778836 & 2.8580448 \\ 7.0620372 & 73.1074313 & 14.1325776 & 7.9450692 & 8.3045775 & 2.2370019 \\ 13.3975753 & 73.3314178 & 12.1845422 & 7.2055806 & 10.2130787 & 1.6653427 \\ 16.0769993 & 72.5543662 & 12.9994102 & 9.3534712 & 9.3423419 & 1.2309049 \\ 14.2911927 & 73.0733779 & 10.4254087 & 9.4854548 & 9.9228695 & 1.5205311 \\ 23.6666769 & 70.6409986 & 10.2313126 & 5.3337347 & 11.8365693 & 2.4196594 \end{bmatrix} \end{matrix} \quad (75)$$

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{matrix} & \begin{bmatrix} 5.7044414 & 5.5578963 & 6.9868360 & 6.4584000 & 5.7933887 & 4.5161369 \\ 4.5749973 & 6.7552642 & 8.1816578 & 6.0000698 & 5.5950412 & 4.2607618 \\ 9.0500073 & 5.3263237 & 6.7552642 & 7.7500201 & 5.7851239 & 4.7930081 \\ 5.2861125 & 6.7157999 & 8.1447437 & 6.2916665 & 5.8347105 & 3.1317135 \\ 5.0124139 & 5.3473697 & 3.3986781 & 5.9167360 & 5.3037201 & 5.3951694 \\ 2.8444507 & 5.4000062 & 6.8289479 & 7.6250267 & 6.7520658 & 5.5204302 \end{bmatrix} \end{matrix} \quad (76)$$

and,

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{matrix} & \begin{bmatrix} 19.1176442 & 27.4540790 & 2.0499042 & 9.1600009 & 4.9453072 & 4.0204556 \\ 51.0451366 & 21.6667352 & 14.0002427 & 5.6338188 & 4.5559199 & .1227371 \\ 19.1179826 & 19.9333141 & 13.2653264 & 5.9151200 & 3.3333232 & 1.9285635 \\ 19.1183018 & 15.8636468 & .3032878 & 6.7708382 & 3.7394733 & 3.5505865 \\ 19.1182063 & 21.1527492 & .3803155 & 5.9686692 & 3.8011670 & 3.5505865 \\ 19.1182407 & 19.0213547 & .5447804 & 5.6605853 & 2.8892746 & 2.4074074 \end{bmatrix} \end{matrix} \quad (77)$$

The Cibecue matrix (75) shows a relatively frequent mean recurrence time for state 1, but more frequent occurrence takes place at an aridity index value below 137. The Pinedale matrix (76) has a relatively even time interval for recurrence and passage from i to j , but the most frequent passage is still approximately three years. The limiting variances for Cibecue, Pinedale, and Show Low are respectively:

$$V = [3.248, .012, .058, .031, .116, .095], \quad . \quad . \quad (78)$$

$$V = [.111, .116, .147, .152, .003, .091], \quad . \quad . \quad (79)$$

$$V = [.003, .037, .320, .089, .129, .078], \quad . \quad . \quad (80)$$

The limiting variances indicate small confidence intervals about the mean number of years in n years that the system will be in each state. This is desirable for prediction and decision making.

Application of the Model: Fillmore-Murray

The establishment model (19) for the Fillmore-Murray area is employed to learn the intervals of aridity index magnitude, giving a probability of 0.75 for seedling establishment. The mean kills experience in this area is high since windrowing is the important factor. Sometimes it is

employed with single chaining and sometimes with double. This makes it difficult to select the most appropriate Markov states. So it was arbitrarily decided to link windrowing with double chaining. Thus the states are figured for the worst kill experience, single chaining, double chaining, and double chaining with windrowing. Due to the paucity of data about single chaining and double chaining kills in the Fillmore-Murray area, the percentages obtained must be treated with caution.

Substituting 30, 38, 60, and 94 percent into (19) defines four states for the aridity index for the techniques listed:

1. $S_1 = I \geq 154$
2. $S_2 = 103 \leq I < 154$
3. $S_3 = 90 \leq I < 103$
4. $S_4 = I < 90$

Precipitation and temperature data have been obtained from 10 Utah weather stations in the area: Loa, Beaver, Milford, Desert Range Experiment Station, Lund, Elberta, Cove Fort, Benmore, Eureka, and Koosharem. The last five of the named stations did not exhibit weather patterns amenable to fitting the same Markov chains described earlier. A great deal of difficulty was experienced in finding transforms other than the "Z" above which would be suitable; otherwise the chains could not be made to converge.

The transition matrix, P, for Loa is:

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} .1666667 & .6666667 & .1666666 & .0000000 \\ .1670000 & .2500000 & .4160000 & .1770000 \\ .2222222 & .3333334 & .2222222 & .2222222 \\ .2000000 & .4000000 & .4000000 & .0000000 \end{bmatrix} \end{matrix}, \quad . \quad . \quad (81)$$

The relatively low probabilities of moving from states 4, 3, and 2 to state 1 indicates generally unfavorable March-June moisture conditions for projects near this station. Movements to states 2 and 3 are the most likely, nevertheless an index suitable for single and double chaining jobs would occur less than half the time. The odds of having weather which is borderline for windrowing two years in a row is nil.

The transition matrix for Beaver follows next:

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} .8181818 & .0000000 & .0000000 & .1818182 \\ .2000000 & .4000000 & .4000000 & .0000000 \\ .5000000 & .2500000 & .0000000 & .2500000 \\ .0000000 & .6666667 & .3333333 & .0000000 \end{bmatrix} \end{matrix}, \quad . \quad . \quad (82)$$

Again the odds of having a weather index dangerously low for drilling, given a value near 10-20 in year t-1 is nil. The reverse is also true; the odds of a big improvement state 4 → 1 from one year to the next are also nil. Still the general tendency for above average index values during March-June is clearly evident. The odds that an index of 170 or better will be repeated is over 80 percent.

The transition matrix for Milford indicates considerably less favorable spring weather than for Beaver:

$$P = \begin{matrix} & S_1 & S_2 & S_3 & S_4 \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} .3000000 & .3000000 & .2600000 & .1400000 \\ .2500000 & .2500000 & .4000000 & .1000000 \\ .1250000 & .1250000 & .5000000 & .2500000 \\ .1000000 & .4000000 & .3000000 & .2000000 \end{bmatrix} \end{matrix}, \quad . \quad . \quad (83)$$

There is always a 10 to 25 percent chance that any given spring will have moisture patterns that are borderline even for drilling. There is a 50 percent chance that state 3 will repeat, but this is a state that is not associated with a very high weather index.

If the weather in $t-1$ is in state 1, there is a fifty-fifty chance it will remain there or move to state 2 at the Desert Range Experiment Station in year t :

$$P = \begin{matrix} & S_1 & S_2 & S_3 & S_4 \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} .5000000 & .5000000 & .0000000 & .0000000 \\ .0000000 & .2857000 & .4286000 & .2857000 \\ .0000000 & .5000000 & .0000000 & .5000000 \\ .3333333 & .6666667 & .0000000 & .0000000 \end{bmatrix} \end{matrix}, \quad . \quad . \quad (84)$$

Once the index is in state 2, however, the odds are that it will be at a lower level the following year. The odds of moving from 4 to 1 or 2 is 100 percent. In fact, the odds of moving to state 2 are quite good. And since there is less likelihood of moving to 3 in the first place, the danger of having a low index at a critical time (4) is linked to the index being in state 2 in year $t-1$. In general spring moisture patterns are probably better than Milford.

The Lund transition probabilities are similar to Milford's:

$$P = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} .3666667 & .3666667 & .3666666 & .0000000 \\ .4545454 & .2727273 & .2727273 & .0000000 \\ .3666666 & .3666667 & .2444446 & .1222221 \\ .1222224 & .3222221 & .2444446 & .2444443 \end{bmatrix} \end{matrix}, \quad (85)$$

Since the remaining five stations have different Markov chains, the limiting vectors of the previous stations will be listed first. They are for Loa, Beaver, Milford, Desert Range Experiment Station and Lund:

$$W = [.2256546 \quad .4321234 \quad .3422222 \quad \text{NEGLGBL}] \quad . \quad . \quad . \quad (86)$$

$$W = [.6532108 \quad .0981325 \quad .2100182 \quad .0386385] \quad . \quad . \quad . \quad (87)$$

$$W = [.255555 \quad .2500000 \quad .4255555 \quad .0688890] \quad . \quad . \quad . \quad (88)$$

$$W = [.1568000 \quad .4326913 \quad .1985020 \quad .2120067] \quad . \quad . \quad . \quad (89)$$

$$W = [.2125683 \quad .5903216 \quad .1703821 \quad .0267280] \quad . \quad . \quad . \quad (90)$$

In general the long run probabilities are for states 2 and 3 to occur. Beaver is the only station of the five showing good probability of state 1 over the long run.

The mean first passage time matrices are now given for the five stations in the same order as previously.

$$M = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} 4.4315632 & 2.0321654 & 7.3685491 & \text{NEGLGBL} \\ 3.1032635 & 2.3141786 & 2.386878 & 8.7135421 \\ 7.3862513 & 6.3154257 & 2.9220321 & 10.71854 \\ 6.5321438 & 3.7158432 & 2.9185321 & 9.48327 \end{bmatrix} \end{matrix}, \quad (91)$$

$$M = \begin{matrix} & S_1 & S_2 & S_3 & S_4 \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} 1.5308012 & 12.318542 & 11.768321 & 6.3218345 \\ 2.3218654 & 1.1903310 & 3.3317533 & 15.653218 \\ 1.9838983 & 7.3812581 & 4.7614532 & 8.7653214 \\ 9.8915891 & 2.5432158 & 5.9186542 & 25.880912 \end{bmatrix} \end{matrix}, \quad (92)$$

$$M = \begin{matrix} & S_1 & S_2 & S_3 & S_4 \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} 3.9130019 & 3.816423 & 3.7654128 & 15.813251 \\ 4.8196432 & 4.0000000 & 2.4565412 & 17.312565 \\ 6.9187321 & 6.3158751 & 2.3498185 & 13.555215 \\ 7.358881 & 2.1532141 & 2.5556425 & 14.516132 \end{bmatrix} \end{matrix}, \quad (93)$$

$$M = \begin{matrix} & S_1 & S_2 & S_3 & S_4 \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} 6.3775000 & 3.3210200 & 10.006805 & 10.7532810 \\ 20.302030 & 2.3111000 & 7.3325000 & 4.3581291 \\ 19.302030 & 2.5110320 & 5.0377000 & 6.3591200 \\ 21.703020 & 2.1113811 & 22.005120 & 4.7168000 \end{bmatrix} \end{matrix}, \quad (94)$$

$$M = \begin{matrix} & S_1 & S_2 & S_3 & S_4 \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} 4.7043703 & 3.8196542 & 3.7913251 & 47.8318784 \\ 2.8191835 & 1.6939918 & 6.1532156 & 48.0109315 \\ 2.7145602 & 3.7194321 & 5.8691611 & 31.7613251 \\ 8.7913824 & 2.4321325 & 5.8132653 & 37.4139479 \end{bmatrix} \end{matrix}, \quad (95)$$

The recurrence time of an index of 154 or above is far better for Beaver than any of the other stations. This will be achieved practically

every year. In contrast better than six years will be required to recur in state 1 at the Desert Range Experiment Station.

The remaining five weather stations do not have recorded weather patterns that allow interpretation on a basis of the probability of moving from state i to j in one year's time. Most of them are recurrent chains which hinge on moves from month to month during the critical season. In some cases the moves are continuous. Only long-run probability matrices (which are transforms of estimated transition matrices) could be developed. They are somewhat analogous to the "M" matrices above, that is, they contain only recurrence information. Elberta is presented first:

$$H(N) = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} .6250000 & .3750000 & .0000000 & .0000000 \\ .3340000 & .0000000 & .3330000 & .3330000 \\ .0000000 & .0000000 & 1.000000 & .0000000 \\ .0000000 & .0000000 & .0000000 & 1.000000 \end{bmatrix} \end{matrix}, \quad (96)$$

Since the movement of the index is discrete the matrix is read as before, i.e., there is a .375 chance of moving from state 1 to state 2 (once in state 3 or 4 it reoccurs in the same state). But the difference is that this holds every year. This means that if the index starts in March in state 2, the reoccurrence in that state in April will be nil. The absorbing probabilities in states 3 and 4 mean that the rest of the season will carry through (March-June) in the same range of the index. Each season the probability of I > 154 reoccurring in Elberta Station will be .624, and so on.

Cove Fort is interpreted the same way only there are no absorbing probabilities to consider. State 4 does not exist; no index lower than 90 occurs for that season.

$$H(N) = \begin{matrix} & S_1 & S_2 & S_3 \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .9090909 & .0000000 & .0909091 \\ .0000000 & .0000000 & .0000000 \\ .6977732 & .0000000 & .3022268 \end{bmatrix} & , & . & . & . \end{matrix} \quad (97)$$

There were a number of gaps in the Benmore data available and they were filled using Monte-Carlo methods. The generated data fit well with precipitation but not so well with temperatures. Also the Z transformation would not work because the chain was continuous. A variation of a Laplace transform was found to be able to detect convergence.

The Benmore long-run probabilities mean that if a beginning is made at a point in time in March, there is a continuous movement to a reoccurrence of state 1 (only can start in 1) with probability of .4321 or to state 3 with a probability of .567. In state 3 the move is continuous to a reoccurrence of 3 or .25 to state 4. Once in 4 the index remains for the rest of the season. Otherwise index passage may repeat many times.

$$H(N) = \begin{matrix} & S_1 & S_2 & S_3 & S_4 \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \end{matrix} & \begin{bmatrix} .4321000 & .0000000 & .5679000 & .0000000 \\ .0000000 & .0000000 & .0000000 & .0000000 \\ .0000000 & .0000000 & .750000 & .2500000 \end{bmatrix} & , & . \end{matrix} \quad (98)$$

Koosharem has little data and interpretation of the long-run probabilities which must be made with even more caution than in the case of other estimations. This is a continuous time Markov similar to

Benmore except that the Z transform on the transition matrix was suitable.

$$H(N) = \begin{matrix} & s_1 & s_2 & s_3 & s_4 \\ \begin{matrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{matrix} & \begin{bmatrix} .4537000 & .0000000 & .5063000 & .0000000 \\ .0000000 & .0000000 & .0000000 & .0000000 \\ .0000000 & .0000000 & .9337000 & .0663000 \\ .0000000 & .0000000 & .0765000 & .9235000 \end{bmatrix} \end{matrix}, \quad (99)$$

There is a 49 percent chance of remaining with an index of 154 or greater and a 51 percent chance of moving to one of $90 \leq I < 103$. Once the movement through March to June goes into state 3, there is a 93 percent chance of staying in this state and 7 percent of moving to the lowest state. The average index is not bad for this station, but project in the area was not planted too well.

The estimated $H(N)$ for Eureka must be interpreted with even more caution. The chain resisted all attempts to make it converge. Finally, all the data for the years 1953-1955 were eliminated to secure convergence. Again this is continuous.

$$H(H) = \begin{matrix} & \begin{matrix} S_1 & S_2 & S_3 & S_4 \end{matrix} \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{matrix} & \begin{bmatrix} .5060201 & .3291321 & .0824239 & .0824234 \\ .8200007 & .1000002 & .0399995 & .0399996 \\ .8500000 & .0750000 & .0650000 & .0100000 \\ .8750000 & .1140000 & .0110000 & .0000000 \end{bmatrix} \end{matrix}$$

This shows a long run probability of a good spring index. A normal index for the area is 180 or well above 154. If the movement of March through June goes to lower indices there is a movement back with good probabilities. Drought occurs in the August-October period.

Forage yield response

Theoretical considerations. The grass plant, once it has been established as an independent organism, enters upon a stage of vegetative proliferation. This stage continues until the plant forms the reproductive organs and flowers. This is the longest growth period of the plant. What happens to the range grass plant in this vegetative state is of utmost importance to stockmen and rangeland managers.

As in seedling establishment, photosynthesis is the important growth activity. The rate of photosynthesis is influenced by temperature, while water provides the nutrients necessary to maintain growth if photosynthesis is active. Water also acts as a cooling agent in the process of transporting nutrients from soil to cell. Excessively high temperatures means a high rate of "evapotranspiration" which in turn may mean death to the grass plant. Low temperatures mean growth suspension. This assumes a given plant adaptability. It is reasonable, therefore, to assume that, even in the presence of adequate moisture, growth as a function of temperature is initially subject to positive, but decreasing, marginal products. It is also reasonable to assume that as the plant obtains greater levels of growth, more of the input mix (nutrients) is needed to maintain the same rate of growth.

Another important variable is the utilization of vegetative portions of the grass plant by range animals. The region of the photosynthetic activity is located in the leaves. When animals eat the leaves down to the crown, photosynthesis and thereby the rate at which food is produced, is impaired. It is assumed, therefore, that as the stocking rate is increased for a fixed grazing area, grass production decreases.

Development of the variables. The theoretical consideration of the response of range grass to temperature, water, and forage utilization suggests the need for measurement of these variables. Water and temperature measurement have already been discussed. However, since only cross-sectional data for range grass production is available, the combination of precipitation and temperature into an index takes on a new form. For prediction purposes, published normal temperatures and precipitation are used. Normals for the critical moisture period corresponding to the various areas of the study are grouped and averaged and then combined in the Ångström aridity index (16).

The normal index is computed from the data for precipitation and temperature printed at the bottom of the tables for individual weather stations, as part of Climatological Data, U. S. Weather Bureau (1960). The values for each month are used in Oury's program (Appendix 2.e.). Values for the appropriate critical period are given by the program. It is necessary to utilize the index computing program because it weights each month's value according to variance from the mean. The results are averaged to give the normal aridity index for the March-June or August-September periods. The normals for the stations most likely to be used with the models presented here have been listed in Appendix 2.e.

To learn which of the averaged months contributes most to the normal index (which might be important for selecting project planting dates because the best interval will be different between stations) is a task yet to be carried out. A computer must be used to solve out by logs and the results are not available for this present report.

Forage utilization is measured by the percent of the average production per acre utilized at given average stocking rates. The stocking rate, usually in terms of acres per animal unit month, is converted to animal unit months per acre, then multiplied by an animal unit month forage requirement (1000 pounds in the following models), to give the amount of forage utilized. This is then converted to a percentage.

Since all the seeding projects had unequal establishment, there is need for a measurement of the affect of seedling establishment on subsequent growth. It is assumed that the probability generated by the establishment model provides a measure of attained level of growth from the emergence process. The associated establishment probability estimates for any selected site and for each eradication technique are used as independent variables.

The dependent variable, grass production, was measured in terms of increased air-dry forage production per acre due to range improvement. All things equal, good establishment probabilities should be linked to relatively high production. But measured figures in vigorous grass stands could be low because a large percentage of individual sites might be covered with downed tree slash from the control process. Therefore, the forage estimates were adjusted downwards for slash percentages. Since expected kill percentages only enter into the production model via the probabilities generated in the establishment model, there is no automatic reverse compensation for this correction. This creates an inheritant structural error within the production models, the consequences of which must be borne in mind. Some correction factor must be introduced as a side calculation. For example, if the predicted production level appears

fairly high and the planned conversion site has a good deal of tree density, the prediction must be reduced. An idea of the magnitude of such correction can be obtained by reference to the historical results shown in Table 6.c.3. of part A of this report.

The generalized model. To test the theory that grass yield is a function of forage utilization, seedling establishment and weather affects, a linear model is employed using cross sectional data. The model is expressed as:

$$\hat{Y} = \sum_{i=1}^3 \beta_i X_i + \epsilon_i \quad . \quad . \quad . \quad . \quad . \quad (101)$$

Where:

$\hat{Y}$ = grass yield in pounds per acre (dry-weight).

β_i = regression coefficients.

X_1 = average pattern of utilization from time of establishment to 1965 (expressed in percent of forage utilized).

X_2 = probability of seedling establishment as estimated from the probit model.

X_3 = Angstrom aridity index using normal precipitation and temperatures.

ϵ = disturbance term.

The model, as expressed, estimates the response of forage yield to two variables capable of policy control and the uncontrolled variable, weather. Managers can, by manipulation of the policy variables, tip the balance of nature in favor of grass production, within the limits of given expected weather conditions.

Empirical application of the model. The model is applied to data from the Monticello-Durango, Cedar City-Caliente, Sitgreaves-Ft. Apache

and Fillmore-Murray areas previously studied in the case of establishment and weather movement. The production data is for the 1965 growing season for all of the areas.

Application of the model to the Monticello-Durango area yields the estimated response equation:

$$\hat{Y} = -528.762 + 450.288X_2 + 6.289X_3, \quad . \quad . \quad . \quad . \quad (102)$$

where:

X_2 = estimated probability of establishment March-June.

X_3 = Ångström aridity index using normal precipitation and temperatures.

Utilization (X_1) for the Monticello-Durango data is not significant. The Monticello Bureau of Land Management office has cut the stocking rate on seedlings of low productivity and the Durango office stocks their seedlings at the same rate. Therefore, no cross-sectional variation in utilization data is present. The estimating equation is such that production is zero when the estimated probability of establishment falls below .50 and the aridity index is less than 47.

The coefficient of determination for (102) is .557 and the partial correlation coefficients of increased production with the estimated probability of establishment and again with the aridity index are respectively .590 and .714. The test of the regression coefficients jointly, using the F-distribution yields a calculated F-value of 8.794. This gives evidence that the regression coefficients jointly are significantly different from zero at the $\alpha = .01$ level using 2 and 21 degrees of freedom. A test of the regression coefficients separably gives evidence that β_2 is significantly

different from zero at the $\alpha = .10$ level, and β_3 significantly different from zero at the $\alpha = .01$ level in both cases using 1 and 21 degrees of freedom.

The Cedar City-Caliente area has variation in the utilization data since three Bureau of Land Management offices have charge of the seeding projects and vary the stocking rates. The estimated response equation for this area is:

$$\hat{Y} = -1157.036 - 305.818X_1 + 2357.020X_2 + 2.715X_3, \quad . \quad . \quad (103)$$

where:

X_1 = percent forage utilized.

X_2 = estimated probability of establishment.

X_3 = March-June $\bar{A}$ ngström aridity index using normal precipitation and temperatures.

The coefficient of determination for the model is .713 and the partial correlation coefficients of increased forage yield with forage utilization, estimated establishment probability and the aridity index are, -.396, .780, and .530 respectively. A joint test on the regression coefficients, using 3 and 20 degrees of freedom, yields a calculated F-value of 16.525. The model is significant at the $\alpha = .01$ level. A test on the individual regression coefficients indicates β_1 to be significantly different from zero at the $\alpha = .10$ level, β_2 significant at the $\alpha = .01$ level, and β_3 again significant at the $\alpha = .10$ level.

Again the estimated equation is such that production is zero if X_2 is held constant at .49, or a value below .49.

The response equation, when applied to the Sitgreaves-Ft. Apache

area, yields the estimate:

$$\hat{Y} = + 370.955 - 452.719X_1 + 51.247X_2 + .844X_3, \quad . \quad . \quad . \quad (104)$$

Where X_1 , X_2 , and X_3 are the same as in (103). The coefficient of determination for the model is .869 and the partial correlation coefficients of increased forage yield with forage utilization, estimated establishment probability and the aridity index are -.620, .698, and .812 respectively. A joint test on the regression coefficients yields a calculated F-value of 22.1809 which gives evidence that the model is significant at the $\alpha = .01$ level, using 3 and 10 degrees of freedom. Separate tests on the regression coefficients individually indicate β_1 to be significant at $\alpha = .01$, β_2 significant at $\alpha = .05$, and β_3 significant at $\alpha = .05$ level. The equation is arranged the same as (102) and (103) with the exception of the intercept which is positive. The coefficient for the aridity index variable is smaller, since the aridity indexes are generally high for the area.

When applied to the Fillmore-Murray area the regression equation is significant for the model, but X_2 is not. X_3 is significantly different from zero at the $\alpha = .01$ level. Again utilization values that were obtainable were so constant that the variable adds nothing to the model. The response equation is:

$$\hat{Y} = 61.874 + 61.166X_2 + 6.714X_3, \quad . \quad . \quad . \quad (105)$$

where X_2 is the conditional probability of establishment and X_3 is the weather index computed on the basis of area normals. The coefficient of determination for the model is .71. Calculated values for the F-tests follow: for the model, 7.1 at 3 and 16 degrees of

freedom; for β_3 , 8.56 at 1 and 16 degrees of freedom. The standard errors are such that predictions from the model must be interpreted with caution.

Recapitulation

The objectives of this section have been to attempt creation of a framework to evaluate seedling establishment and subsequent production, utilizing only cross-sectional ecological data and time series for weather. Obviously, this is not an easy task. Given the available information the approach has been to identify specific policy variables influencing both objectives. These variables can only be manipulated within the limits of given weather patterns. The decision to opt for range improvement is based on the odds a land manager is willing to accept concerning weather conditions in the future. Thus a third objective which this study attempts to accomplish is estimation of the movement of weather patterns and the associated probabilities.

The results of the analysis, using data for establishment, production, and the nonpolicy variable, weather, associated with the four areas concerned in encouraging, but conditional. There is need for demonstration that each of the three models explains its respective relationships in one of the four areas better than any other model. This demonstration, however, is beyond the scope or data available for this study. It is disappointing to find that the study area must be broken into such small units to accommodate the models developed. Several regions such as Vernal-Craig or Grand Junction-Montrose do not have large numbers of projects to begin with. Moreover,

1965 was a wet, late year; and many sites were simply not, or could not be visited by the ecological team. There are not enough projects, even including Forest Service-Utah Fish and Game ones to do anything for much of the central area of Utah north of Kanab. There are no projects other than those of the Caliente district in Nevada. The Farmington projects did not work out well when added to the Durango-Montecello area or with the Navajo, but were too few to stand alone.

In terms of data, what is needed are adequate time series covering annual or seasonal forage production and utilization. This means that study plots are not satisfactory; plantings re-visited only once every decade will not do; and pasture tests designed for animal weight or nutrition projects are likely to be operated on an inconsistent basis.

The establishment model. Since there appears to be some lack of consensus among range managers concerning measurement of seedling establishment, but more importantly, because no records of measurement of seedling emergence on the many sites visited have been made, establishment can only be estimated by the use of a dichotomous (yes or no) dependent variable. Opinions of success or failure were obtained by interview. The weakness of this method is obvious. As the independent variables change in degree, the variance changes also. The probit model is superior to other approaches since limits are set and constant variance is forced. The applicability of the model is in the generated probabilities. The probabilities are a tool, useful for present improvement decision making with consideration of the chances for improvement success in the future. A more desirable model is an extension

of the probit model to a measure of degree of success rather than being confined to the limits of a dichotomy. Insufficient data, however, dictates the use of the dichotomous model.

To use the model in specific instances requires that at least one eradication technique be imagined. Probable kill must be computed by employing the chaining or cabling models presented by Rivers (Part A, p. 128; also Section 2.d. infra). A choice of seed planting depth or rate or both must be made depending upon the area considered. Various levels of probability may be chosen as acceptable as far as entering the probit tables are concerned, but it should be recalled that all of the Markov chains developed to explain weather movements are based on the assumption that .75 probability of establishment is the chosen value.

The Markov chain. The Markov chain is an applicable tool for explanation of time-ordered phenomenon. In this study, it explains the time-ordered movement of the aridity index relatively well. The asymptotic properties of the chains derived show that relatively fast convergence occurs as the transition matrices are raised to successive powers. The asymptotic properties of most of the data also comply with the assumptions of the first order Markov chain. It must be kept in mind, however, that the chain derived is an indicative, not a conclusive, explanation of weather patterns. The initial states are defined in terms of the establishment model, both for a given range improvement technique and the aridity index used. The chain when expressed in these terms, gives a good indication of what technique should be followed given the probabilities of aridity

index movement. The limiting variances indicate relatively good estimation of the weather movement probabilities for three of the four areas studied. The Sitgreaves-Ft. Apache area did indicate a much smaller variance than the other three, however.

Attempts to link weather phenomena to crop response obviously get extremely complicated in a hurry. Real competence in handling, analysing and interpreting stochastic processes is far beyond the scope of most researchers. In the Fillmore-Murray instance there are differences in the probability generation on the same side of the state of Utah. This is certainly suspicious-- but it is the best that can be done given the meager knowledge available of weather phenomena. It is not an uncommon occurrence to discover that a Markov chain will fit the weather patterns of a station quite well, yet at some point the chain breaks and another style chain is necessary. It may then be terribly difficult to say just which chain gives a better description of the weather movement. This is almost certainly a factor in the Fillmore-Murray data, and is caused, at least in part, by the cyclonic nature of the weather in western Utah. Moving towards Colorado and southeast of New Mexico or south of Arizona, is a movement away from cyclonic weather patterns towards a monsoon situation. It may be pretty dry at times, but it is known when the moisture will come.

The transition matrices, limiting vectors, and mean first passage matrices may have some intrinsic worth for use with other dry land crops requiring moisture in the same critical periods assumed for the present study. Allowance must be made for differences in the

aridity index levels which would guarantee establishment success in individual cases.

Determination of which state t-1 is in requires some hand calculation. The mean temperatures and precipitation for each of the months, March-June must be inserted into equation (16) and the resulting index values averaged. This is done for the weather station nearest the planned project area. The average index is located within the range of states already defined for the weather station in question. This is not too accurate, but unless the computed value is on a borderline between states, crude calculation will not matter too much. When further information is available about the contribution of each month to the average index (mentioned above) some weights may be attached during the averaging process.

Forage response model. With the exception of the estimated equation for the Monticello-Durango and Fillmore-Murray areas, all the estimated coefficients, corresponding to each variable hypothesized to influence grass production, indicate a significant relationship. Data dictated the reduction of the Monticello-Durango and Fillmore-Murray models to just the establishment probability and aridity index variable.

Forage utilization is a primary factor hypothesized to influence forage production in the Sitgreaves-Ft. Apache area. Grazing control is sometimes hard to apply on Indian Reservations and grazing often is heavy.

In the Monticello-Durango area, relatively high conditional probabilities occur. The estimated model indicates probability of

establishment to be a prime factor explaining the high forage increases in this area.

The windrowing-drilling technique so influences the data from the Fillmore-Murray area that the conditional probability variable entering into the production response model does not have the influence that the normal aridity index variable has. Low precipitation and high temperature are the big factors during the latter part of the March-June season.

The estimated equations in all four cases indicate the expected sign for the regression coefficients. These coefficients show an inverse relationship of forage increase with forage utilization. Positive relationship is shown for forage increase with establishment probability and the aridity index. The models are not as reliable as is desirable. It is possible that some better explanatory variables could be developed. The question which would have to be answered in any case, of course, would be whether or not such variables had any theoretical justification. It is also possible that the data should be set up in other than regression form, some kind of production function for example. But it is unlikely that enough observations on the variables considered in this study are available as yet.

2.d. Selecting Optimum Conversion Practices

In Chapters 7 and 8 of Part A it was observed that the ecological team always encountered "successes" when visiting conversions that were windrowed and drilled. This is certainly the safe method anywhere in the northern portion of the study area. In fact, in another recent report, it is the sole practice recommended when seeding is contemplated (5, p.83 ff.). But safe and "optimum" are not the same thing. The desirable course of action is to obtain the best returns per dollar spent. And, as the historical review has shown, certain portions of the study area seem to lend themselves to less elaborate treatment. In addition, it is sometimes difficult to obtain the necessary funds to carry out expensive, full-scale land treatment operations. The question is, given the production possibilities associated with each of the contemplated treatments, which will yield the greatest net return?

Having made this point, however, it must be admitted that, in areas west of the Wasatch Range, risks inherent in treatments other than drilling may be unacceptable. In that case, only certain portions of what follows will be useful (i.e., some of the chaining cost and seeding rate data and parts of the discounting model). Thus, it may be that the establishment model presented in the section above will be the main contribution to the windrow and drilling case. What follows may have greater relevance for evaluation of alternatives short of complete tree eradication and drilling.

An initial requirement is estimates of potential grass production following eradication by any technique contemplated. The establishment

and production models of the previous section will fulfill this requirement to the degree they prove accurate under further use or test.

But it must be emphasized that it is not necessary to use the production estimating system presented earlier, it is only necessary to introduce estimates from some "outside" source. In fact, this is all that can be done in those areas for which a grass establishment-production model could not be worked out. In such instances, the linear programming step (below) must be by-passed.

The final step in choosing the "optimum" technique rests upon a chain of reasoning that turns out to be rather lengthy. In fact, the discounting framework is a good deal more complex than might be expected from a reading of Cotner's 1963 article (8). The reason for this is that he envisages a tree "invasion" situation, whereas in the model presented here an initial chaining of mature trees precedes a "regrowth" (analogous to invasion) period and the associated decision to re-chain. In addition, none of his work considers situations where seeding is part of the treatment.

Cotner's model or a modification of the last stage of the one to be presented below would be appropriate in areas where trees have already been controlled and re-growth has started.

The procedure for determining an optimum conversion practice is set forth in a 4-part analysis. The first establishes the relationship between the dependent variable (removal cost) and the independent variables (density, soil, slope, tree heights, and number of acres). The second part maximizes grass establishment probabilities for each technique, given costs. In the third attention is turned to the effects

of tree re-growth on grass production, and the time interval until re-eradication will be necessary. The final section brings all portions of the model together and contains an example.

Existence of a relationship between cost per acre for the eradication and site characteristics such as density and height of the pinyon-juniper trees, soil, slope, and number of acres will serve as the primary foundation for determining the optimal conversion practice to be used on a particular site. This makes possible prediction of costs per acre for each of several alternative control techniques.

Given these costs per acre, the total cost associated with the maximum grass establishment for each feasible technique must be determined. All the cost steps detailed below must be repeated for each technique considered for a planned eradication.

For each technique, establishment probability will be maximized subject to the constraints of kill, seed cover, seed rate, and weather index. Within each technique there is some flexibility with respect to seed rate, kill and seed cover. These can be altered (within constraints) to achieve the maximum probability of establishment. This maximum probability of grass establishment is then linked to a prediction of forage production.

But due to encroachment of residual trees the levels of forage production may fall over time. Therefore, it is necessary to develop a relationship that will lead to the calculation of the point in time where grass production reaches the minimum allowable limit. With the levels of kill for each technique already determined for a particular site, it is possible to calculate the number of trees not affected by

each eradication treatment. The relationship between production and crown canopy makes possible the calculation of the absolute minimum allowable grass production and the corresponding percent of crown canopy. Since these percentages are directly related to average crown diameters, it is possible to find the relationship between average tree height and average tree diameter. Once heights are known the average age of the trees not affected by original eradication can be established. Subtracting this age from the age of the trees at the time of original chaining yields the replacement or re-control interval.

These steps establish a time horizon over which the computation of the value of net benefits for each technique may be made. The result is an array of present values. The technique yielding the maximum of the maximum present values of net benefits is, therefore, defined as the optimum conversion practice for the particular site in question.

Predictive Cost Models - In order to determine the relationship between cost per acre and site characteristics, the primary hypothesis to be tested was that changes in tree densities, soil texture, roughness of terrain, and number of acres result in increased eradication costs.

Land treatment reports from various agencies were the prime data source. The project's ecological team could only visit a relatively small number of completed projects. For obvious reasons, force account costs could not be used. This restricted the number of useful observations.

An a priori selection of variables thought to be important in explaining the variation in eradication cost are: size of the project, density of the trees, soil type, and terrain. In the case of bulldozing the height of the trees was also considered as an independent variable.

Costs per acre for control on projects ranging from 0-1,000 acres were much higher than for projects ranging from 1,000-4,000. It appears that once a certain size of project is reached total costs per acre tend to remain constant. The higher costs on small projects can be partially explained by the fact that on large projects contractors' fixed costs are spread over a larger number of acres. Also, the width of the swath in chaining might be less due to greater influence of irregular shape when working smaller projects.

Density of tree stand, soil type, and roughness of terrain all affect cost in the same manner. The increase in density of the stand acting along with changes in soil type and roughness of terrain increases the time required to eradicate an acre, causing an increase in the average variable cost of the contractor. Fuel, oil, grease, repairs for the tractor, and operator cost are also variable costs, but due to the scope of this particular study these are treated as captured in bid costs.

In the bulldozing case the time required to push tall trees is greater than that required to push small trees. Cotner and Jameson (1959, p.7) regressed tree height in feet against time required in hours and arrived at a correlation coefficient of 0.640. Therefore, this increase in time required to push tall trees results in a higher cost per acre for the control.

In this analysis emphasis was given only to arriving at a predictive model for each of the three major techniques: a) single chaining, b) double chaining, and c) bulldozing.

For purposes of tightening up the model and increasing its predictability, it was necessary to divide the study area into two

parts in the single chaining case: a) Arizona and Nevada projects, and b) Colorado, New Mexico, and Utah projects. This division was made on the basis of cost and site characteristics.

In the double chaining case it was not necessary to make this type of division. The examples used in this analysis were mainly located in the Utah-Colorado area, with a few in Arizona. The sites located in Arizona were selected on the basis of how well their site characteristics coincided with those in the Utah-Colorado area. Bulldozing on the other hand was taken from sites only in the Arizona area and as a result, no division was necessary.

Information concerning the number of trees per acre for particular sites was not available in the single and double chaining cases. As a result, percent of the site occupied by pinyon-juniper was used. In the bulldozing case information pertaining to the number of trees per acre on the sites in question was available and in turn this figure was used.

It was also necessary to code soil and terrain types. Coding of soil was accomplished by summarizing all the soil types of an area and the technique costs associated with them. They were then assigned a numerical number (1,2,3,...) with the lowest average cost receiving the lowest numerical value. It was necessary to derive two separate codings, one for the Arizona-Nevada area, and one for Colorado, New Mexico, and Utah.

Terrain was coded in a similar fashion. Sites characterized by level slopes were coded as ones and those characterized by rolling to rough terrain as fours. Appendix B contains tables showing the numerical code for each particular type of soil and slope encountered in the study area.

Tree height data were not directly available for the bulldozing model. Known tree height data from related sites in the project areas had to be used.

Single Chaining - Arizona and Nevada area - Determination of a predictive control cost model for the Arizona and Nevada area was based on 18 observations. In the regression model the variables were defined as follows:

$\hat{Y}$ = control cost per acre.

X_1 = acres.

X_3 = soil type.

X_4 = terrain or slope.

X_5 = density of pinyon-juniper.

The resulting regression equation is:

$$\hat{Y} = .2715 + .00009X_1 - .000000024X_1^2 + .0413X_3 + .672X_4 + 3.119X_5. \quad (1)$$

The analysis of variance and significance tests are presented in Table 1.

Table 2.d.1. Analysis of variance for single chaining model, Arizona-Nevada area

Source of variation	Degree of freedom	Mean squares	Regression coefficients	F
Total	17	.81728E-00 ^a		
B(0)	--	--	.271498E-00	
B(1)	1	.49366E-01	.934625E-04	
B(2)	1	.23097E-00	-.241559E-07	
B(3)	1	.43422E-01	.413086E-01	
B(4)	1	.33835E+01	.672003E-00	
B(5)	1	.68101E-00	.311944E+01	
Model	5	.23550E+01		13.34*
Residual	12	.17656E-00		

Coefficients of determination = .85.

*Significant at 5 percent probability level.

^a.8172E-00 is equivalent to .81728.

Calculating the "F" statistic for mean squares due to model yields a value of 13.34. Comparing this calculated value with the tabular value of "F" with (5,12) degrees of freedom at the 5 percent probability level indicates that the calculated value exceeds the tabular value. Therefore, the hypothesis that the model does not significantly explain the variability in the dependent variable (cost) is rejected. As a result, the alternative hypothesis that the model does significantly explain the variation in the dependent variable is accepted.

To test the null hypothesis that $\beta_1 = \beta_2 = \dots = \beta_5 = 0$ substitute the values of R^2 , K, and N into equation (1). Comparison of the calculated "F" value with the tabular value (K-1 and N-K degrees of freedom at the $\alpha = .05$ level) results in the rejection of the null hypothesis and acceptance of the alternative hypothesis that $\beta_1 \neq \beta_2 \neq \dots \neq \beta_5 \neq 0$.

Single Chaining - Colorado, New Mexico, and Utah area - The predictive control cost model for this area is based on 23 observations. The variables in this model were defined in the same manner as that used for the Arizona and Nevada area.

The resulting regression equation is:

$$\hat{Y} = .3673 + .000568X_1 - .0000002X_1^2 + .3322X_3 + .4937X_4 + .4705X_5. \quad (2)$$

The analysis of variance and significance tests are presented in Table 2.

Calculating the "F" statistic for mean squares due to model yields a value of 5.13. Comparing this calculated value with the tabular value of "F" (5,17 degrees of freedom at the 5 percent probability level) indicates that the calculated value exceeds the tabular value. Therefore, the hypothesis that the model does not significantly explain

Table 2.d.2. Analysis of variance for single chaining in the Colorado, New Mexico, and Utah area

Source of variation	Degree of freedom	Mean square	Regression coefficient	F
Total	22	.8010E-00		
B(0)	--	--	.36727E-00	
B(1)	1	.1053E-00	.56774E-03	
B(2)	1	.9643E-01	-.20014E-06	
B(3)	1	.3128E+01	.33217E-00	
B(4)	1	.3256E+01	.49373E-00	
B(5)	1	.5338E-01	.47051E-00	
Model	5	.2121E+01		5.13*
Residual	17	.4131E-00		

Coefficient of determination = .602.
 *Denotes significance at 5 percent probability level.

the variability in the dependent variable is rejected. As a result, the alternative hypothesis that the model does significantly explain the variation in the dependent variable is accepted.

To test the null hypothesis that $\beta_1 = \beta_2 = \dots = \beta_5 = 0$ substitute values of R^2 , K, and N into equation (1). Comparison of the calculated "F" value with the tabular value (K-1 and N-K degrees of freedom at the $\alpha = .05$ level) results in the rejection of the null hypothesis and acceptance of the alternative hypothesis that $\beta_1 \neq \beta_2 \neq \dots \neq \beta_5 \neq 0$.

Double Chaining - All areas - The predictive control model for double chaining employs the same variables as in the single chaining cases.

The resulting equation is:

$$\hat{Y} = 1.412 - .000613X_1 + .000000069X_1^2 + .086X_3 + .893X_4 + 2.86X_5. \quad (3)$$

The analysis of variance and significance test are presented in Table 3. This analysis was based on 21 observations in the Utah, Colorado, and Arizona areas.

Table 2.d.3. Analysis of variance for double chaining

Source of variation	Degree of freedom	Mean square	Regression coefficient	F
Total	21	.98499E-00		
B(0)	--	--	.14116E+01	
B(1)	1	.13786E-00	-.61270E-03	
B(2)	1	.12562E-00	.69303E-07	
B(3)	1	.55012E-00	.86000E-01	
B(4)	1	.25116E+01	.89309E-00	
B(5)	1	.11441E+01	.2858E+01	
Model	5	.29491E+01		7.945*
Residual	16	.37122E-00		

Coefficient of determination = .713.

*Denotes significance at the 5 percent probability level.

Calculating the "F" statistic for mean squares due to model yields a value of 7.945. Comparing this with the tabular value of "F" (5,16 degrees of freedom at the $\alpha = .05$ level) leads to rejection of the null hypothesis that the model does not significantly explain the variation in the dependent variable. The acceptance of the alternative hypothesis is therefore accepted.

Test of the null hypothesis that $\beta_1 = \dots = \beta_5 = 0$ is performed as before. Comparing the tabular value of "F" with the calculated value of "F" results in rejection of the null hypothesis and acceptance of the alternative hypothesis that $\beta_1 \neq \beta_2 \neq \dots \neq \beta_5 \neq 0$.

Bulldozing - To arrive at a predictive model in this case it is necessary to add an additional independent variable (tree height). The variables used were defined as follows:

$\hat{Y}$ = control cost per acre.

X_1 = acres.

X_3 = soil type.

X_4 = slope.

X_5 = density of pinyon-juniper.

X_6 = tree height.

X_7 = tree height squared X_6^2 .

The resulting regression equation takes the following form:

$$\hat{Y} = -.027 - .0000857X_1 + .00000002X_1^2 + .007X_3 + .0352X_4 + .000086X_5 + .1997X_6 + .00016X_6^2 \quad (4)$$

The analysis of variance and significance tests are present in Table 4.

This analysis was based on 24 observations.

Table 2.d.4. Analysis of variance for bulldozing

Source of variation	Degree of freedom	Mean square	Regression coefficient	F
Total	23	.20362E+01		
B(0)	--	--	-.27421E-01	
B(1)	1	.17454E-02	-.85773E-04	
B(2)	1	.33626E-03	.22009E-07	
B(3)	1	.17249E-02	.70449E-02	
B(4)	1	.14841E-01	.35213E-01	
B(5)	1	.12532E-02	.85586E-04	
B(6)	1	.76031E+00	.19972E+00	
B(7)	1	.73006E-03	.16345E-03	
Model	7	.66772E+01		114.00*
Residual	16	.58453E-02		

Coefficient of determination = .98

*Significant at the 5 percent probability level.

Calculating the "F" statistic for the mean squares due to model yields a value of 17.75. When this is compared with tabular "F" (7,16 degrees of freedom at the $\alpha = .05$ level) the null hypothesis is rejected. The alternative is accepted.

Testing the null hypothesis that $\beta_1 = \dots = \beta_5 = 0$ with equation (1) results in the rejection of the null hypothesis and acceptance of the alternative hypothesis that $\beta_1 \neq \beta_2 \neq \dots \neq \beta_5 \neq 0$.

With the preceding models it is possible to predict various eradication costs for a particular site. It now becomes necessary to determine the total cost associated with achieving the maximum grass establishment likelihood associated with each eradication possibility.

Determination of the Total Costs Associated with Maximum Forage Establishment

The total cost (for each feasible technique) of obtaining maximum establishment probability is found indirectly through the use of linear programming procedures. Programming is used to "force out" the levels of each activity within a general technique, exact seed depth or pounds per acre, etc. The individual costs associated with such levels are then summed. This total is the least cost of obtaining the postulated probability. The Simplex method has been employed in the examples which follow.

Selection and Development of Constraints - Predictive grass establishment models for various areas occupied by pinyon-juniper woodland have been developed in section 2.c. For each technique these particular models are expressed as functions containing the following variables: kill, seed cover, seed rate, and weather. As yet, none of the probabilities that could be obtained as shown in 2.c. have been maximized. The purpose of this section is to illustrate how this can be accomplished.

From section 2.c., the establishment model associated with a technique for the particular area in question can be measured as follows. Let equation (5) be such a model (subject to kill, seed cover,

seed rate and weather constraints) so that the values of β are known. Equation (6) can be optimized by straightforward linear programming procedures. This is set up in the form most applicable to the La Sal province.

$$Z_{\max} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4, \quad . \quad . \quad (5)$$

subject to:

$$\beta_1 X_1 = b_1, \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$\beta_1 X_1 + \beta_2 X_2 \leq b_2, \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$\beta_2 X_2 \leq b_3, \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\beta_3 X_3 + \beta_4 X_4 \leq b_4, \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$\beta_4 X_4 = b_5, \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$$\beta_2 X_2 + \beta_4 X_4 \leq b_6, \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

$$\beta_3 X_3 \leq b_7, \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where:

Z = probability of establishment.

X_1 = percent of kill.

X_2 = seed rate.

X_3 = seed cover.

X_4 = weather index.

Derivations of the constraining conditions are based on the following reasoning. Constraint (6), which is the kill constraint, was developed by utilizing the regression equation shown by Rivers in Part A (p.128). These have the form:

$$\log \hat{Y}_{D.C.} = \log_{10}(16.5) + .4035 \log (k), \quad . \quad . \quad . \quad (13)$$

$$\log \hat{Y}_{S.C.} = \log_{10}(6.18) + .6113 \log (k), \quad . \quad . \quad . \quad (14)$$

where:

$\hat{Y}_{S.C.}$ = expected percent kill for single chaining.

$\hat{Y}_{D.C.}$ = expected percent kill for double chaining.

k = the percent of the stand ≥ 7 inches in diameter.

Solving the above equation for a particular k_i yields corresponding expected values of kill, namely $\hat{Y}_i = X_1$.

Due to the lack of a predictive model for kill in the bulldozing case, it was necessary to resort to mean kill values. Therefore, it was assumed that the expected value of kill in all cases for bulldozing was the mean kill associated with it. This assumption was based on the fact that for any given density the desired kill can be obtained if the associated cost is incurred. Substituting the expected value of kill into constraint (6) yields:

$$\beta_1 X_1 = C_1,$$

where:

C_1 = bulldozing constant for the particular site in question.

The "b" values in the remaining constraints were determined in the following manner. On non-windrowed projects in Utah and Colorado it was found that as percent kill increased the seed rate decreased reaching an asymptote at 7 pounds per acre. Setting kill equal to 100 percent and multiplying it by its coefficient and adding it to seven multiplied by its coefficient, yields the value of b_2 .

In the case of b_4 , it was observed (mainly in the La Sal province) that when X_4 is at its maximum, X_3 is equal to zero. Substituting the levels of these variables into (10) yields the numerical value of b_4 .

The value for b_6 was determined in a similar fashion. The value of X_2 was set equal to 7 pounds per acre when X_4 was at its average value for the Monticello-Durango area. Solving for b_6 with these particular values yields its numerical value.

In the case of b_5 , the weather index constraint, it is necessary to determine the index that is most likely to occur in the growing season following the time eradication is planned. This value is determined by methods set forth in 2.c. above.

The values of b_3 and b_7 are defined as the maximum allowable value that X_2 and X_3 can take on multiplied by their respective coefficients. In the case of b_3 , the value of X_2 was relaxed enabling it to range up to any level considered feasible. However, b_7 is set at 3 inches because this was selected as the maximum depth at which good germination may be achieved.

In areas where the establishment model must be expressed as a function of a combination of the original variables (say Fillmore), it is necessary to eliminate the irrelevant constraints. Also in areas where kill falls between the limits of 70 to 100 percent and where the expected weather index falls between the mean weather index and its maximum value, it is necessary to eliminate constraints (7), (8), (9), and (12). In the situation where the value of kill falls within the 70-100 limit (defined range) and the expected weather index value falls outside of its defined range (between mean and maximum values), it is necessary to eliminate constraint (12).

In situations where both value of kill and expected weather index fall within their defined ranges, it was observed that 7 pounds

of seed yields a high level of establishment. Therefore, whenever this situation arises seed rate (X_2) is automatically taken to be 7 pounds per acre. Examples will be given later of all these adjustments.

Establishment models have only been worked out for a few of the regions within the present study area. More ecological data are necessary before further progress can be made on this problem. In districts or regions lacking a model, the procedure will be to estimate (for each feasible clearing technique) what levels of seeding and covering will be necessary to achieve a desired degree of establishment. No programming is used. The various activity levels are simply costed as shown in the following section. Yields must be predicted as well. These values are introduced as Y_p 's in the discounting procedure shown under the heading, "Presentation of Complete Model" below.

Selection and Development of Variables for Minimum Total Cost Function -

Total cost for each technique is defined as a function of out-of-pocket cost (cost of eradication, cost of seed, and cost of seed application). The cost of eradication (CK) is calculated by substituting the site characteristics into the predictive cost models for the particular site in question. When considering bulldozing it is necessary to set up a proportion between the mean tree density (107.9 trees/acre) to the initial cost given by the cost model and the actual tree density associated with the site in question to CK. Solving for CK yields the cost of eradication for this technique.

Cost of the seed is determined by taking the seed rate that maximizes grass establishment times the price per pound of the appropriate species of grass for the area. This can be determined arbitrarily or

through use of the programming models to be discussed below.

Cost of the seed application is determined in the following manner. If the level of X_3 generated by the programming model to be discussed below is less than or equal to one inch, the application technique is taken to be aerial broadcasting. The cost associated with this technique is the mean cost for all the projects studied that were aerial seeded. If the level of X_3 is greater than 1 and less than 3, the application technique to be used is drilling. The cost associated with this particular technique is also the mean cost for all the projects studied that were seeded by drilling methods.

Given the above values, it is possible to define total out-of-pocket costs for each technique as:

$$TC = CK + CS + CA, \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Where:

TC = total cost.

CK = cost of eradication.

CS = cost of seed.

CA = cost of applying seed.

Derivation of an Optimal Solution for Several Hypothetical Situations -

The following hypothetical situations illustrate how to set up the programming problem. Case I is an illustration of the problem when the establishment model is expressed as a function of all the variables given in equation (5). Case II illustrates establishment where either or both the level of kill and expected weather index fall within the 70-100 and mean-max ranges respectively. Case III has in its make-up interaction of the independent variables. It must be borne in mind

that the examples are strictly hypothetical in nature, that is, all the coefficients (β 's) in the establishment model employed were arbitrarily chosen. In real life the coefficients must be obtained from appropriate models for each area shown in 2.c. above (if such models exist).

Case I is an example of a hypothetical situation where the establishment model is a function of all the variables contained in equation (5). The technique tested is single chaining for which the predicted kill given the percent of trees ≥ 7 inches, is 60 percent. Setting up the following restrictions makes it possible to employ linear programming procedures to determine levels of each X_i that will maximize the probability of establishment.

$$\begin{aligned} .231X_1 &= .1386 \\ .231X_1 + .026X_2 &\leq .4130 \\ .026X_2 &\leq .2600 \\ .16X_3 + .00117X_4 &\leq .4352 \\ .00117X_4 &= .1498 \\ .026X_2 + .00117X_4 &\leq .6172 \\ .16X_3 &\leq .48 \end{aligned}$$

$$Z_{\max} = -.07 + .231X_1 + .026X_2 + .16X_3 + .00117X_4 \quad . \quad (16)$$

$Z_{\max} = .764$ and the level of the variables yielding this value are:

$X_1 = .60$, $X_2 = 10.0$, $X_3 = 1.8$, $X_4 = 128.0$. The low kill can only be off-set by increasing the seed rate and drilling in this hypothetical case. It is necessary to convert $Z_{\max}$ from index terms (Infra p. 34) into probability terms. This is accomplished by referring to Table 1b in Anderson and Bancroft (1952, p.382) which yields the area under the normal curve. In the above case $Z_{\max}$ in probability terms is

equal to .77, that is, given the previous values of X_1 , X_2 , X_3 and X_4 the range manager has a 77 percent chance of obtaining grass establishment.

It is now possible to calculate the total out-of-pocket costs associated with this probability of grass establishment. If the site characteristics (not given in this example) are introduced into the appropriate single chaining model, the predicted bid cost can be ascertained. Suppose this is \$2.50 per acre (CK) to achieve a 60 percent kill.

The seed cost (CS) may be calculated by multiplying X_2 by the cost per pound of the particular species of grass to be used. For this example the cost of grass per pound was set at \$.25 per pound. Multiplying $X_2 = 10$ by \$.25 yields $CS = \$2.50$.

In the case of seed cover it was found that X_3 was greater than one which implies broadcasting of the seed. Therefore, the mean cost for windrowing and drilling was substituted as CA. Substituting CK, CS, and CA into equation (16) yields:

$$TC = \$2.84 + \$2.50 + \$13.50$$

$$TC = \$18.84$$

Case II involves combinations of X_1 and X_4 falling both within and without their defined ranges. The first combination is where X_1 falls inside and X_4 falls outside. The appropriate constraint relationships are:

$$.231X_1 = .1894$$

$$.026X_2 \leq .2600$$

$$.16X_3 + .00117X_4 \leq .4352$$

$$.00117X_4 = .1498$$

$$.026X_2 + .00117X_4 \leq .3996$$

$$.16X_3 = .4800$$

$$Z_{\max} = -.07 + .231X_1 + .026X_2 + .16X_3 + .00117X_4 \dots (17a)$$

(Remember that the β 's must always come from the establishment model.)

$Z_{\max} = .8770$ and the level of the variables yielding this value are:

$X_1 = .81$, $X_2 = 9.6$, $X_3 = 1.8$, $X_4 = 128.0$. Converting Z into

probability terms yields $Z_{\max} = .79$.

Again drilling is necessary. The calculation of the total cost associated with maximum probability of grass establishment now proceeds in the same fashion as that for Case I.

Where X_4 falls within the limits previously defined and X_1 falls outside its defined limits, the problem takes the following form:

$$.231X_1 = .1894$$

$$.231X_1 + .026X_2 \leq .4130$$

$$.026X_2 \leq .2600$$

$$.16X_3 + .00117X_4 \leq .4352$$

$$.00117X_4 = .1498$$

$$.16X_3 \leq .4800$$

$$Z_{\max} = -.07 + .231X_1 + .026X_2 + .16X_3 + .00117X_4 \dots (17b)$$

Determination of the optimal solution now proceeds using the simplex system and costs are found as before.

If X_4 and X_1 both fall within the defined limits the constraints and the objective function reduce to the following form:

$$.16X_3 + .00117X_4 \leq .4352$$

$$.00117X_4 = .1498$$

$$.16X_3 \leq .48$$

$$Z_{\max} = .16X_3 + .00117X_4 \dots (17c)$$

After determining the optimal solution for $Z_{\max}$ in equation (18), substitution of the particular levels of X_3 and X_4 along with $X_1 = .81$ and $X_2 = 7.0$ must be made back into equation (16). The resulting value of Z must then be converted into probability terms. The calculation of the total cost associated with the maximum probability of grass establishment then proceeds in the usual manner.

Case III is an illustration of how to set up the programming problem when the establishment model from 2.c. above does not contain all of the variables presented in equation(5). If the particular establishment model under question is a function of kill and weather alone, the problem is arranged in the following manner:

$$.231X_1 = .1386$$

$$.16X_3 + .00117X_4 \leq .4352$$

$$.00117X_4 = .1498$$

$$.16X_3 \leq .48$$

$$Z_{\max} + .07 + .16X_3 + .00117X_4 \dots (18)$$

$Z_{\max}$ is determined by using the simplex method.

In examples such as the above, where seed rate falls out of the establishment model, it is necessary to use the seed rate that is generally accepted in the area to calculate TC. This variable dropped out of the establishment model because observations of the seed rate

used remained nearly constant for all projects in a given area (say, Monticello). After the CS has been determined, calculation of TC can proceed as before.

Establishing the Re-Control Date

One of the characteristics of the Pinyon-Juniper type is that even if control plots are completely cleared of trees, there is a tendency for re-growth, this re-growth presents the need for future maintenance or re-eradication. Because of the time it takes the trees to develop, it was necessary to consider only one cycle, that is the initial control plus re-control. The length of the cycle has a bearing upon the time horizon over which to discount benefits. To find the re-control date it is necessary to test the following hypotheses:

- (a) That there exists a direct relationship between average crown diameter and total tree height.
- (b) That there exists a relationship between total tree height and average age of the tree.
- (c) That there exists a relationship between time and crown canopy.
- (d) That there exists a relationship between crown canopy and production.

Selection and Development of Variables - Observations on the variables mentioned were obtained by summarizing data collected by the Bureau of Land Management's ecological sampling team in two field seasons. In general the work of Rivers was followed (Part A, Chapters 4 and 6).

But for the present purposes the division of relationships into species and site classes was ignored. The relationships used in this part of the analysis are general and were developed solely for purposes of simplification. In order to develop a relationship between average crown diameter and total average tree heights, it was necessary to summarize the data collected.

Tree height data were summarized in terms of total average tree heights and the age data were the average ages of the trees at the 1 foot level. The value for tree age at the 1 foot level was obtained through the method presented by Rivers (Part A, pp. 135-143).

Given the number of trees per acre not affected by the initial control, it was possible through the age-density, percent crown canopy relationship developed by Rivers (Part A, pp. 135-155) to determine the relationship between time and crown canopy percentage when the minimum tolerable grass production is reached (Part A, Chapter 7).

The relationship between production and crown canopy was tested by summarizing the data collected (Part A, Chapter 7). In order to obtain a horizontal asymptote at high crown canopy percentages, a reciprocal function was fitted.

Tree height vs. average crown diameter - The 64 observations involved in this analysis were the averages of all tree heights and average crown diameters on 64 plots. The resulting regression line took the following form:

$$\hat{Y} = 4.56 + 1.32X. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

where:

Y = total average tree height for the site

X = average crown diameter. And

$$X = 2 \frac{\pi i}{\dots} \dots \dots \dots \dots \dots \dots (20)$$

where:

$$X_i = \frac{Ch}{NS} ,$$

Ch = percent crown canopy at minimum tolerable gross production level (converted to square feet per acre)

NS' = predicted number of trees following eradication.

The resulting analysis of variance and test of significance are presented in Table 2.d.5.

Table 2.d.5. Analysis of variance for average crown diameter and tree height

Source of Variation	Degree of Freedom	Mean Squares	Regression equation	F
Total	63	.11586E+03		
B(0)	--	--	.45556E+01	
B(1)	1	.686604E+04	.132104E+01	
Model	1	.686605E+04		983.2*
Residual	62	.698313E+01		

Coefficient of determination = .941.

*Denotes significance at .05 level.

Tree height vs. age - Age data employed in this analysis was the age at the 1 foot level. Tree height was measured in total tree height. The analysis was based on 64 observations which were average tree heights and ages for the 64 plots. The resulting regression equation took the following form:

$$\hat{Y} = 3.31X^{1.31} \quad (21)$$

where:

$$\hat{Y} = \text{age at the 1 foot level of NS}$$

X = tree height

NS = number of trees originally on site

The analysis of variance and test of significance are presented in Table 2.d.6.

Table 2.d.6. Analysis of variance of age vs. tree height

Source of Variation	Degree of Freedom	Mean Squares	Regression Equation	F
Total	63	.370109E-00		
B(0)	--	--	.119598E+01	
B(1)	1	.199738E+02	.131159E+01	
Model	1	.199738E+02		370.57*
Residual	62	.539203E-01		

Coefficient of determination = .857

*Denotes significance of the .05 probability level.

Production vs. crown canopy - Development of a relationship between forage production and crown canopy was accomplished by dividing the study area up into three provinces: a) Escalante-Sevier, b) La Sal, and c) Coronado. The boundaries for these provinces were based on differences in geology, topography, soil parent material, climate and vegetation as established by Isaacson (Part A, Chapter 3). Figure 3.b.1 (Part A) is an illustration of these boundaries.

The analysis was carried out by summarizing the data collected by the BLM sampling team. The regression equation for each of the provinces

is given in Table 2.d.7.

Table 2.d.7. Regression equations for production vs. crown canopy

Province	Number of Observations	Regression Equation		Mean Squares	R ²
Escalante	18	$+\hat{Y} = 6.402 + \frac{7.208}{*X}$	(22)	307.98	.7125
La Sal	20	$\hat{Y} = 5.788 + \frac{17.954}{X}$	(23)	764.36	.9331
Coronado	18	$\hat{Y} = 45.22 + \frac{3.8019}{X}$	(24)	317.48	.7288

$+\hat{Y}$ is equal to expected forage production
 *X is equal to percent crown canopy.

Use of the reciprocal transformation in analyzing the production vs. crown canopy data made it possible to determine at what level production approaches a horizontal asymptote. This feature will be utilized later on and discussion will be temporarily delayed.

Analysis of variance and tests for significance of the models of all the provinces above led to rejection of the null hypothesis that the models did not explain the variation in the dependent variable. Therefore, the alternative hypothesis that the models do significantly explain the variation in the dependent variable was accepted.

Relation of time and crown canopy. The analysis of crown canopy and re-growth time was determined by deriving a relationship between crown canopy percentage and time for each range of NS' within each site class. Rivers based site classification on the tree height of the 10 inch

diameter class read from his height/diameter curves (Part A, p. 85).

The following table uses his site class breakdown for Pinyon.

The regression equation for each of these classifications are presented in Table 2.d.8.

Table 2.d.8. Regression equation for time vs. crown canopy

Site Class (Pinyon)	Interval of NS'	Regression Equation		R ²
24'-31'	0-100	$\hat{X} = *.00007S^{1.60}$	(25)	.8649
	100-200	$\hat{X} = .00014S^{1.56}$	(26)	.8405
	200-up	$\hat{X} = .000159S^{1.55}$	(27)	.8056
18'-23'	0-100	$\hat{X} = .00009S^{1.485}$	(28)	.8987
	100-200	$\hat{X} = .0009S^{1.649}$	(29)	.9752
	200-300	$\hat{X} = .00014S^{1.61}$	(30)	.9413
	300-up	$\hat{X} = .000137S^{1.70}$	(31)	.9839
11'-17'	0-100	$\hat{X} = .00065S^{1.102}$	(32)	.8279
	100-up	$\hat{X} = .00047S^{1.24}$	(33)	.9583

$\hat{X}$ is equal to percent crown canopy
*S is equal to re-growth time.

The analysis of variance for each site class and interval indicated that in all cases the "F" test led to the rejection of the hypothesis that the models were not significant. Therefore, the alternative hypothesis is accepted.

Summary. The previous relationships makes it possible to set up two methods for determining the re-control date. The re-control date for the purposes of this study is defined as the time that re-eradication should take place. Method I employs the general relationships (adopted from Rivers) between tree height, age, and crown diameter. Method II is the more straight forward method for determining the re-control date,

employing only the time-crown canopy and forage production-crown canopy regression equations.

1. This method of determining the mechanically fixed date of re-control (T_r) is based upon the following relationships: a) the relationship between percent of kill and percent of the stand greater than or equal to 7 inches in diameter; b) the relationship between average crown diameter and tree height; c) the relationship between tree height and average tree age; and d) the relationship between production and crown canopy.

Given a certain percent of the stand equal to or greater than 7 inches in diameter makes it possible to determine the expected value of kill for each feasible techniques. Substituting the expected values of kill into the following relationship:

$$NS - E(K_j)(NS) = NS' \quad . \quad . \quad . \quad . \quad . \quad (34)$$

where:

NS = number of trees before eradication

$E(K_j)$ = expected value of kill for the j th treatment ($j = 1.....N$) yields the number of live trees not eradicated.

Determination of the date where percent crown canopy causes production to approach a horizontal asymptote in equations (22), (23), and (24) is accomplished by putting confidence limits on α , where α is defined as follows:

$$\text{Limit } (f(x)) = \alpha$$

$$x \longrightarrow \infty$$

where:

$$f(x) = \alpha + \frac{\beta}{x} = \text{amount of forage production} = \gamma$$

X = percent of crown canopy.

The intersection of the upper bound of the confidence limit with the function [in effect] sets the maximum physical time interval (T_r) between control dates. Given the percent crown canopy (22, 23, 24) it is possible to substitute the average crown diameter of the trees into equation (19). This yields the total tree heights. The resulting value is substituted in turn into equation (21) yielding the age at the 1 foot level when NS' reaches the level of crown canopy (Ch) where production of forage reaches the minimum allowable limit.

Defining T_r as the number of years until the mechanically set date for re-control for the j^{th} treatment:

$$T_r = F(Z_2) - f(Z_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

where:

$f(Z_2)$ = age when trees reach Ch.

$F(Z_2)$ = age of the trees less than 7 inches in diameter at the time of original eradication.

2. The second method relies upon: a) the relationship between time and crown canopy, and b) production and crown canopy. Given a certain percent of the stand greater than or equal to 7 inches in diameter it is possible to determine the expected value or kill for each of the techniques. Substituting this value into equation (34) yields the number of trees following eradication. Entering Table 2.d.8 with this value plus the site class characteristic of the particular

site permits selection of the equation that represents the appropriate time-crown canopy relationship.

By referring to Table 2.d.7 the equation that represents the appropriate production-crown canopy relationship for the area in question may be obtained. Substituting the correct relationship between time and crown canopy into the relationship between production and crown canopy yields production as a function of time.

$$\hat{Y}'_p = \alpha + \frac{\beta}{\alpha' s t} \quad . \quad . \quad . \quad (36)$$

Defining the production function as $\hat{Y}'_p$ and taking the limit $\hat{Y}'_p \rightarrow \infty$ yields the horizontal asymptote α . Establishing confidence limits on α and selecting the upper limit as a minimum level of production yields the age that the NS' will have to reach before production reaches its minimum allowable limit. Equation 35 is then solved for T_r .

T_r is the maximum number of years between control dates, but the optimum re-control date may fall anywhere between the time of initial control and the dates set by T_r determination of this optimum date will now be considered.

Presentation of Complete Model. The complete model for determining optimum conversion practices in the Pinyon-Juniper type consists of a combination of the following submodels: a) the chaining models, b) maximum grass establishment and associated total cost model, and c) the re-control model. (But it is stressed again that b, the linear programming step, is optional).

Once a site has been selected to receive control measures, it is possible through the use of the above models to determine: a) the cost of eradication, b) the maximum grass establishment probability and its associated total cost, c) the mechanically fixed date for re-control, and d) the resulting forage production.

Once specific values are known for each of the above variables, it is possible to calculate the specific point in time ($t_i \leq T_r$) where present value of net benefits reaches a maximum value for each technique. Once this point in time has been determined, the optimum date for re-control can be defined as the point in time where present value of net benefits reaches a maximum. The technique yielding the maximum of the maximum present values of net benefits is, therefore, the optimum practice. Finding the optimum practice thus requires a run-through of all the models for each of several techniques.

If a number of sites are involved this same procedure provides a method whereby selection of the site yielding the maximum present value of net benefits can be determined. For example, if there are three potential sites in question and the optimum technique for each site has been determined, all that remains is the comparison of the maximum present values of the net benefits. The site yielding the maximum of the maximum present value of the net benefits is, therefore, defined as the optimum site.

Complete Model. For convenience in developing the complete model, the following notation is adopted:

TC_{oj} = the initial cost of control for the j^{th} treatment.

TC_{rj} = the cost of re-control of the j^{th} treatment.¹

$Z(E)$ = the establishment model for the area in question (section 2.c)

$\mathcal{L}_{ij} z_{ij}^{X_{ij}}$ = constraining conditions on $Z(E)$.

P_i = pounds of air dry forage given by production model of section 2.c or from any other source.

K_{oj} = the expected initial chaining cost associated with the j^{th} treatment.

K_{rj} = the expected re-control chaining cost associated with the j^{th} treatment.

$PV(NB)_j$ = present value of expected maximum net benefits.

$PV(B)$ = present value of initial benefits.

$PV(B')$ = present value of re-control benefits.

$PV(L)$ = present value of the loss in benefits by delaying replacement until time t_x .

t_o = time of initial control, t'_o = number of years of deferment.

t_x = optimum time for replacement.

t_r = the mechanically fixed date for re-control.

V_f = value of increased forage², V_d = value of increased and original forage during deferment.

For a given set of site characteristics, it is possible to generate values of K_{oj} through the use of equations (1) through (4). The kills

¹In order to arrive at a figure for TC_{rj} an adjustment to allow for seedling growth is made by adding one tree a year, from the time of initial control up to the time of re-control, to NS' . This value in turn is substituted into the predictive cost equations as the figure for density. In the cases where density is expressed as a percent, the conversion factor is $.001 = 1$ tree.

²As forage is expressed in pounds per acre, it is necessary to convert to AUM's per acre. This is accomplished by dividing the amount of forage by 1000 (or other value appropriate for the type and season of grazing) and multiplying by the "appropriate" price of an AUM.

associated with the K_{oj} 's in the double and single chaining case may be calculated by plugging the value for the percent of the stand greater than or equal to 7 inches in diameter into equations (13) and (14). The bulldozing case necessitates setting the expected value of kill equal to its mean value for the observations studied. In the case of bulldozing it is necessary to revert back to the proportion set up between mean density to expected value of cost and the density of the site under question to CK. The value for CK is determined now by solving the above proportion for CK.

Maximizing $Z(E)$ subject to $X_{ij} \leq X_{ij}$ yields the value or level of X_2 (seed rate) and X_3 (cover depth). Multiplying X_2 by the cost of the seed per pound of the species of grass desired and by setting CA equal to the cost per acre implied by the depth of X_3 yields the values of CS and CA respectively. If the depth implies aerial seeding, CA is equal to \$.47, and if it implies drilling CA is equal to \$1.50 plus an allowance for windrowing of something near \$12 per acre for contract jobs. Taking the summation of CK, CS, and CA yields the total cost associated with the maximum probability of grass establishment. Production values are another matter.

Glover (sec. 2.c) in predicting production of grass on converted Pinyon-Juniper woodlands, developed a production function for grass which is expressed in terms of percent utilization, weather index, and probability of grass establishment. His resulting equation takes the following form:

$$P_i = f(u,w,E), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (37)$$

This is a general model for prediction of adapted grass species production. But the crown canopy - production relationships presented above are derived from native grass production data. Thus a means must be found to utilize both models simultaneously. There are two ways this might be done, but each has short-comings. Both approaches rest upon the assumption that adapted grass species are affected at least as much by re-growth of canopy cover as are native grasses; even if predicted adapted species production exceeds the "best" experience for native production by two or three times, once the trees have re-grown to some heavy crown canopy percentage, adapted production will be no higher than native production under similar circumstances (6, 1967). This assumption means that the number of years that it would take to reach the minimum allowable amount of forage production is about the same for either native or adapted grasses.

The first approach is detailed in an example shown in the appendix to this section and only essentials are given here. The important step is to make an adjustment in the B values of equations 22, 23, 24, if the expected initial amount of production exceeds the maximum values observed for native grasses in the chosen area. These adjustments serve the purpose of forcing the functions of Table 2.d.7. to decrease or fall more rapidly to stay near the time limits for re-growth that would be set with only native grass data. When the relationships of table 2.d.8 are substituted into those of table 2.d.7 the generalized production takes the form shown in (36).

If confidence intervals are put on α and the upper limit is set equal to the equation 36, solving for x yields the age that the unkilld

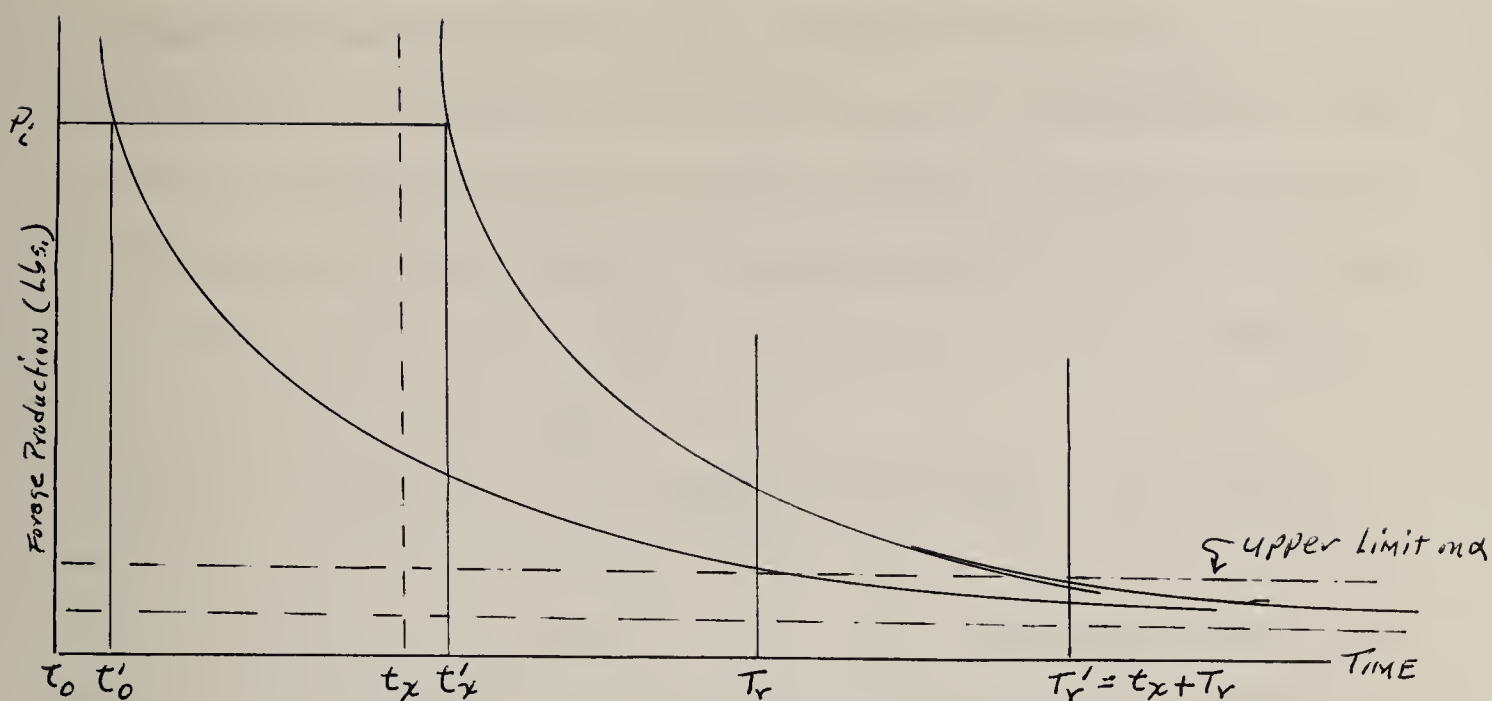


Figure 2.d.1. Graph illustrating the forage benefits accruing due to initial control and re-control.

trees (NS') will have to reach before grass production will have reached its lowest acceptable limit. Once the age is known, the age of NS' at time of original chaining can be subtracted, thereby establishing the longevity interval, T_r .

The present value of gross benefits is greater the longer re-control is held off; at the same time, expected costs of re-control rise over time due to increases in tree size.¹ More importantly, there is a "loss" of potential benefit from putting off re-control for extreme

¹More accurately, re-control costs are high when trees are smaller because they must be hand chopped or burned, costs fall to some minimum and then rise as the trees continue to mature. Re-control is only considered after passage of enough time to permit use of heavy mechanical equipment.

periods of time. Thus, a balance must be struck between a stream of benefits that falls over time and costs (or losses) which will rise. The optimum date for re-control will be at a date $\leq T_r$. Therefore, for any data t_x between t_o and T_r the present value of an initial tree control operation plus one additional re-control can be determined by solving:

$$PV(B) = V_f \left[P_i e^{-rt} dt + \frac{1}{(1+r)^{t'_o - t_o}} \int_{t'_o}^{t_x} \hat{Y}_p e^{-r(t_x - t'_o)} dt \right] \quad (38)$$

$$PV(B') = \frac{V_f}{(1+r)^{t_x}} \left[P_i e^{-rt} dt + \frac{1}{(1+r)^{t'_x - t_x}} \int_{t'_o}^{t_r} \hat{Y}_p e^{-r(t'_r - t'_x)} dt \right] \quad (39)$$

$$PV(L) = \frac{V_f}{(1+r)^{t'_o}} \int_{t'_o}^{t_x} (P_i - \hat{Y}_p) e^{-r(t_x - t'_o)} dt \quad (40)$$

and,

$$PV(NB)_j = [PV(B) + PV(B')] - [MTC_{oj} + \frac{MTC_{rj}}{(1+r)^{t_x}} + PV(L) + V_d] .$$

The point (t_x) in time where $PV(NB)$ reaches a maximum is therefore the optimum time for re-control to take place for the j^{th} technique. This value must be found by using a computer to test experimental values of t_x . The same process must be repeated for each technique under consideration. The technique yielding the maximum of the maximum $PV(NB)$ is therefore the optimum conversion practice.

It is important to note that the calculation of $PV(NB)$ is based on the following assumptions: a) the technique employed for re-control is the same as that employed at time t_o , b) that P_i for re-control is equal to P_i for the initial control, c) that the loss in benefits encountered between initial control and re-control are the only losses considered relevant, and d) that total cost is a function of MTC_{oj} , MTC_{rj} (N., p. 122 infra), and $PV(L)$.

Solution of the system of integrals shown above is obviously not something for a desk calculator so a hand method will now be presented.¹ Let the same notation be employed and the upper limit be calculated on α as before, using the functions as developed for native grass (22, 23, 24). This has been done for all possible values of T_r as shown in table 2.d.9. Let P_i and t'_o be the coordinates of one point and T_r and the upper limit on α be the coordinates of another. These may be connected by a straight line rather than a curvilinear function, at little sacrifice of accuracy. This may be done on graph paper as illustrated in figure 2.d.2. In addition, if t_x is tested at intervals of at least one year, discrete rather than continuous discounting may be employed.

¹Use of a computer is still far the easiest, once a program is written.

Table 2.d.9. Values for Age of NS' After Regrowth as Computed for
Average Initial Ages at Time of Chaining*

Interval NS		<u>Escalante-Sevier</u>			<u>LaSal</u>			<u>Coronado</u>		
		Initial Age	Regrowth Age	Tr.	Initial Age	Regrowth Age	Tr.	Initial Age	Regrowth Age	Tr.
Value of Upper Limit for		11.602			15.688			47.48		
Pinyon Site Class										
24'-31'	0-100		483	403		573	463		547	467
	100-200	80	363	283	110	433	323	80	412	332
	200-up		347	267		414	304		394	314
18'-23'	0-100		658	555		791	656		752	649
	100-200	103	345	242	135	407	272	103	389	286
	200-300		302	199		358	223		342	239
	300-up		226	123		265	130		254	151
11'-17'	0-100	120	1,045	925	175	1,338	1,163	120	1,250	1,130
	100-up		626	506		780	605		734	614

*Initial ages adapted from Part A, fig. 4.b.3., 7" DBH.

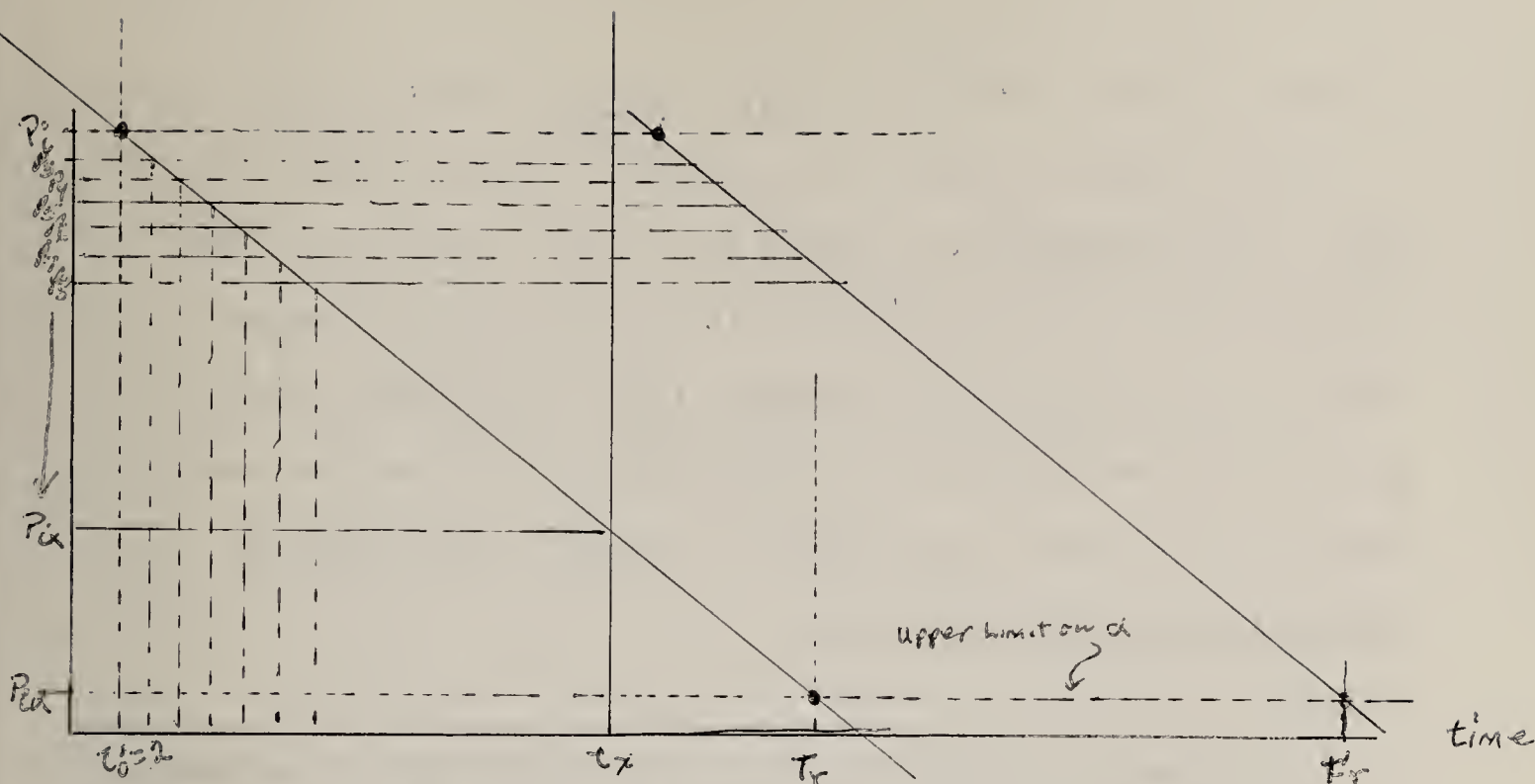


Figure 2.d.2. Graph illustrating method of computing $P_{i3}, P_{i4}, P_{i5}, \dots$ etc.

Therefore for each iteration of t_x , solve:

$$PV(B) = V_f \left[P_i \left[\frac{1 - (1+i)^{-t_0'}}{1} \right] + \frac{1}{(1+i)^{t_0'}} \left(\frac{P_{i3}}{(1+i)^{t_0+1}} + \frac{P_{i4}}{(1+i)^{t_0+2}} + \dots + \frac{P_{ix}}{(1+i)^{t_x - t_0'}} \right) \right] \quad (41)$$

$$PV(B') = \frac{V_f}{(1+r)^{t_x}} \left[P_i \left\{ \frac{1 - (1+r)^{-t_0'}}{i} \right\} + \frac{1}{(1+r)^{t'_x - t_x}} \left(\frac{P_{i3}}{(1+i)^{t_0+1}} + \frac{P_{i4}}{(1+i)^{t_0+2}} + \frac{P_{i5}}{(1+i)^{t_0+3}} + \dots + \frac{P_{ir}}{(1+i)^{t_r + t_0'}} \right) \right] \quad (42)$$

$$PV(L) = \frac{V_f}{(1+i)^{t'_0 - t_0}} \left(\frac{P_i - P_{i3}}{(1+i)^{t_0'+1}} + \frac{P_i - P_{i4}}{(1+i)^{t_0'+2}} + \dots + \frac{P_i - P_{ix}}{(1+i)^{t_x - t_0'}} \right) \quad (43)$$

$$PV (NB)_i = PV (B) + PV (B') - TC_{Oj} + \frac{TC_{rj}}{(1+i)^{t_x}} + PV (L) + V_d .$$

Again, this equation must be solved for various values of t_x . But this may not be too difficult since the already completed series in (41) and (43) can easily be extended. MTC_{rj} also changes with t_x . If the values for $PV(NB)_j$ are plotted, the t_x where profits reach a maximum can be readily approximated. The whole process must be reiterated for each technique (j).

Examples

The following examples are set forth in four steps: a) estimation of the initial expected cost of eradication, b) estimation of the minimum total cost associated with mechanically fixed maximum grass establishment, c) estimation of the mechanically fixed date of re-control, and d) determination of the optimum date of replacement and the optimum conversion practice. Only in steps (C and D) is it necessary to show two separate examples; steps (A) and (B) are common to each example.

A. Assume the site under question has the following site characteristics: a) density equal to 325 trees per acre with average height of 15 feet. b) sandy clay soil, c) gentle slope, and d) the number of acres to be eradicated is equal to 920 (existing grass production, nil). Given these characteristics the expected costs of single chaining, double chaining, and bulldozing are given by K_{O1} , K_{O2} , and K_{O3} respectively.

$$\begin{aligned} K_{O1} &= .3673 + .0006X_1 - .0000002X_1^2 + .3322X_2 + .4937X_3 + .4705X_4 \\ &= .3673 + .0006(920) - .0000002(920)^2 + .3322(4) + .4937(2) + \\ &\quad .4705(.325) \text{ [equation (2)]} \end{aligned}$$

$$K_{o1} = \$3.56.$$

$$K_{o2} = 1.412 - .0006X_1 - .000000069X_1^2 + .086X_2 + .893X_3 + 2.86X_4$$

$$= 1.412 - .0006(920) - .000000069(920)^2 + .086(5) + .893(2) + 2.86(.325)$$

$$K_{o2} = \$4.17. \text{ [equation (3)]}$$

$$K_{o3} = -.027 - .000085X_1 + .00000002X_1^2 + .007X_2 + .03X_3 + .000085X_4 +$$

$$. . . + .1997X_5 + .00016X_5^2,$$

$$K_{o3} = \$3.26 \text{ [equation (4)]}$$

If it is assumed further that 60 percent of the stand is greater than or equal to 7 inches in diameter it is possible to arrive at the expected value of kill for each technique. Substituting 60 percent into equation (13) and (14).

$$\hat{Y}_{D.C.} = 16.5 (60)^{.4035}$$

$$\hat{Y}_{D.C.} = .85$$

$$\hat{Y}_{S.C.} = 6.18 (60)^{.6113}$$

$$\hat{Y}_{S.C.} = .75$$

$$Y_B = .83$$

where:

$\hat{Y}_{D.C.}$ = kill associated with the technique of double chaining.

$\hat{Y}_{S.C.}$ = kill associated with the technique of single chaining.

$\hat{Y}_B$ = kill associated with the technique of bulldozing.

The value of CK for bulldozing may now be calculated in the following way (CK for D. C. and S. C. equal K_{o2} and K_{o1} respectively):

$$\frac{\text{site density}}{CK_B} = \frac{\text{mean density}}{K_{o3}}$$

$$\frac{325}{CK_B} = \frac{108}{3.26}$$

$$CK_B = \$9.80.$$

B. To facilitate the calculation total cost associated with the mechanically fixed optimum grass establishment, the hypothetical site is assumed to be located in the Monticello area. The establishment model has the following form:

$$Z(E) = -1.47 + 2.57X_1 + .009X_2 - .01X_1X_2$$

where:

$$X_1 = \text{kill} = .85.$$

$$X_2 = \text{weather index} = 200.$$

It is important to note that in the above model seed rate and depth of cover have dropped out of the establishment model. This can be explained due to the fact that in this area, seed rate and depth remain constant over all the projects. It is now possible to set up the constraints in the following manner:

$$Z(E)_{\max} = -1.47 = 2.57X_1 + .009X_2 - .01X_1X_2$$

subject to :

$$2.57X_1 = 2.1845 \text{ (for double chaining)}$$

$$.009X_2 = 1.800.$$

Due to the fact that the variables X_1 and X_2 are defined as .85 and 200 respectively, the programming model reduces down to one of simply substituting these values into $Z(E)$. The value for $Z(E)$ in turn is converted into probability terms through the use of Table 1.b. in Anderson and Bancroft (1952, p. 382). The values of $Z(E)_{\max}$ in probability terms for double chaining, single chaining, and bulldozing are .79, .77, and .78 respectively.

CS may be determined by multiplying seven, which is the amount of

seed that management in Monticello employs, by the price of the specific species of grass. Therefore, $CS = \$2.80$, where the price of grass per pound is assumed to be \$.40. CA in this case was set equal to \$.53 per acre (the mean price of aerial seeding) because aerial seeding was the technique employed in the Monticello area.

The value of TC is obtained by summing CK, CS, and CA for all three cases. Therefore, the TC's for double chaining, single chaining, and bulldozing are given by $TC_{o2} = \$7.29$, $TC_{o1} = \$6.94$, $TC_{o3} = \$13.13$.

C. The expected value of initial production, P_i , may be obtained by substituting the appropriate variables into the prediction equation developed for the Monticello area (p.82 , infra.).

$$P_i = 528.762 - .00277X_1 + 450.288X_2 + 6.289X_3$$

where:

P_i = expected initial production.

X_1 = percent of utilization.

X_2 = probability of establishment.

X_3 = normal weather index.

The values of X_1 and X_3 were determined by means presented in the section above. The value of X_2 used to calculate P_i for each technique was the value resulting from the maximization of $Z(E)$ for each technique. Therefore, the values of P_i for double chaining, single chaining, and bulldozing are 940, 930, and 935 pounds respectively.

From this point the procedure to be followed depends upon whether a computer program is available for the discounting step which follows. It is first supposed that such a program is available. In that case it is necessary to adjust the β value in equation (36) as mentioned earlier (if the expected initial amount of production, P_i , generated

by (37) deviates from the highest value in the data contained in Table 2.e.12, Appendix 2.e). This adjustment is made by setting up the proportion:

$$\frac{\beta \text{ in (22, 23, 24)}}{\text{Max. observed native grass prod. for area}} = \frac{\text{Adj } \beta}{P_i \text{ (37) Initial}}$$

The adjusted β is then inserted in (22), (23), or (24) as appropriate. Then, since there is a relationship between canopy cover and time and between production and canopy, substitution of equations (25), (26), and (27) into (22), (23), and (24) gives a production function of the following form:

$$\hat{Y}'_p = \alpha + \frac{\beta}{\alpha' s^g}, \dots \dots \dots (44)$$

where:

$\hat{Y}'_p$ = forage production,

s = time,

and the other values are as defined in Tables 2.d.7 and 2.d.8.

Allowing for this adjustment of β :

$$\hat{Y}_{PD.C.} = 5.788 + \frac{62.00}{.00007s^{1.60}}, \dots \dots \dots (45)$$

$$\hat{Y}_{PS.C.} = 5.788 + \frac{57.9}{.00007s^{1.60}}, \dots \dots \dots (46)$$

$$\hat{Y}_{PB} = 5.788 + \frac{69.10}{.00007s^{1.60}}, \dots \dots \dots (47)$$

where:

$.00007s^{1.60}$ = crown canopy-time relationship obtained from Table 2.d.8 by assuming site class equal to 24' -31' and NS being between 0-100.

The confidence limits on α are taken from Table 2.d.9 above, but

the T_r 's in the same table cannot be used. New ones must be calculated by solving (39), (40), or (41) where the upper limit value is set equal to Y'_p . Since the upper limit for La Sal province is 15.688 (5.788 + 9.9), the value for T_r can be found for each technique. This is 400 years for double chaining, 370 for single chaining and 385 for bulldozing.

If a computer is not used, three graphs must be prepared, one for each technique. For double chaining the coordinates which must be connected (given the assumptions of the problem) are 940 (P_i) - 2 years (deferment) and 15.688 (min. Prod.) - 463 (T_r for native, Table 2.d.9). The same T_r will be used for the other techniques as well, only the initial production levels will be changed.

Under these assumptions the set up will be as shown below.

$$\begin{aligned}
 PV(B) &= 1.00/AUM \left[\left\{ 940 \left[\frac{1-(1.02)^{-2}}{.02} \right] \right\} + \frac{1}{(1.02)^2} \left(\frac{937}{(1.02)^3} + \frac{936}{(1.02)^4} + \frac{935}{(1.02)^5} \right. \right. \\
 &\quad \left. \left. + \frac{934}{(1.02)^6} + \frac{933}{(1.02)^7} + \frac{932}{(1.02)^8} + \frac{931}{(1.02)^9} + \frac{930}{(1.02)^{10}} \right) \right] \\
 PV(B') &= \frac{100/AUM}{(1.02)^{10}} \left[\left\{ 940 \left[\frac{1-(1.02)^{-2}}{.02} \right] \right\} + \frac{1}{(1.02)^2} \left(\frac{937}{(1.02)^3} + \frac{936}{(1.02)^4} + \right. \right. \\
 &\quad \left. \frac{935}{(1.02)^5} + \frac{934}{(1.02)^6} + \frac{933}{(1.02)^7} + \frac{932}{(1.02)^8} + \frac{931}{(1.02)^9} + \frac{930}{(1.02)^{10}} + \right. \\
 &\quad \left. \dots \dots \frac{15}{(1.02)^{571}} \right) \right] \\
 PV(L) &= \frac{1.00/AUM}{(1.02)^2} \left(\frac{3}{(1.02)^3} + \frac{4}{(1.02)^4} + \frac{5}{(1.02)^5} + \frac{6}{(1.02)^6} + \frac{7}{(1.02)^7} + \right. \\
 &\quad \left. \frac{8}{(1.02)^8} + \frac{9}{(1.02)^9} + \frac{10}{(1.02)^{10}} \right)
 \end{aligned}$$

$$PV(NB)_{DC} = \left[PV(B) + PV(B') \right] - \left[7.50 + \frac{.6.84*}{(1.02)^{10}} + PV(L) + Def. \right]$$

$$= 8.142 + 6.676 - \left[7.50 + 5.61 + .043 + .194 \right]$$

$$PV(NB)_{DC} = \$.29$$

* TCrj Computation--NS' + .001/year from to $\rightarrow$ tx

138 + 10 = 148 trees/acre or 14.8 percent at
date of re-chain.

$$TCrj = 1.412 - .0006(920) + .000000069(920)^2 + .086(5) + .893(2) +$$

2.86(.148) plus seed and application.

$$TCrj = \$3.51 + \$2.40 \text{ (seed)} + \$.53 \text{ (application)}.$$

D. As far as the computer-method is concerned, one iteration is made for each technique to determine present values for sample tx's. These are purely illustrative and may or may not represent the highest present values for each technique. It is supposed that $t_x = 73$ for double chaining, $t_x = 70$ for bulldozing and $t_x = 67$ for single chaining are known to be the "proper" values to maximize net returns. That is, the tx's are assumed to be those which would maximize PV (NB)_j. If Vf (forage value) is assumed to be \$1.00/AUM, with $i = .02$, the maximum PV (NB)'s for double chaining, single chaining and bulldozing are \$33.72, \$33.01, and \$26.21, if the appropriate substitutions are made into (38), (39), and (40). In real life, these results would be recorded (plotted) along with solutions obtained from employing other values for t_x . The t_x yielding the highest value for each technique would be compared to those of other techniques to establish the optimum technique.

The example of the manual calculation system was set up for only one technique (double chaining) and for a short intermal ($t_x = 10$) to

minimize the computations necessary for a solution. (In this method the appropriate substitutions are made into equations (41), (42), and (43).) Two year deferment is assumed and the values for P_i , P_{i3} , P_{i4} etc. are 940, 937, 936, 935, 934, 933, 932, 931, 930 for $t_x = 10$ (reading from the appropriate graph). It is also assumed that there is re-growth (in only 10 years) great enough to require mechanical re-control. So costs of \$4.17/acre plus seed and application will be required for the original chaining and \$3.51 plus seed and application for re-control. It is also assumed that existing production is 100 pounds air dry forage per acre, per year, valued at \$.10/acre.

In this example PV (B') is significantly less than PV (B) even though t_x is only tested at 10 years. And if a value, $t_x = 100$ had been tested, PV (B') would have been over ten times smaller, say \$.60. Gross benefits would have been about \$9.00, while at the same time PV (L) (a loss function) would have been much greater than \$.04. The increase in loss of benefits would have been offset by a much lower present value of re-control costs. And, on balance, it is likely that PV (NB) would have been positive given the data assumptions.

It is clear that, even with very low interest rates, the relevant discounting periods obtained by these models may be immense, too immense for re-chaining to have much weight. They might be shortened, perhaps considerably, if the benefits side of the discounting framework were altered to make adequate allowance for the establishment and growth of seedlings. A crude adjustment of this nature has been made on the cost side. This would require more and better ecological data than are presently available. At the same time it must be recognized that

the relationships derived for canopy cover-time (Table 2.d.8) encompasses ranges or frequency intervals of 100 trees. Thus, if NS' were on the low end of any interval, establishment of up to 100 seedlings per acre has already been allowed for. On this argument it is possible that maximum time horizons would not be much altered from what is shown in Table 2.d.9. In many instances the canopy cover where $\propto$ becomes nearly asymptotic is 50-60 percent or more. Then, given the reciprocal function fitted to the data, the time to reach such percentages is very great.

If the minimum acceptable level of grass production is set by some other arbitrary basis, and at a higher level, say 50 pounds per acre, the discounting time horizon would shorten considerably, and the need for considering re-control costs would be increased. Table 2.d.9 would have to be recomputed. But this would not change the steps in computation systems presented.

As the data now stand, the only possible conclusion is that it is much more important to allow for re-control costs on good sites where for some reason expected kill percentages are low. Otherwise, emphasis should be on the discounted value of benefits and costs associated with initial control. It is also probable that the loss function $PV(L)$ can be ignored unless "maintenance" costs are much lower than currently associated with hand chopping or individual burning. That is, there is no point in worrying about the tree "loss" of a benefit which is less than the cost to secure. After the elapse of a sufficient time period, this would not be a logical argument. But as a practical matter, if the sufficient time were

150-200 years, the discounted value of net benefits of re-control might always be too small to weigh very heavily in the initial investment decision. In short, the odds are that any average seeding will be "lost" due to purely random factors like rodent invasions or due to poor management before re-growth of trees becomes a serious problem.

2.e. Appendixes for Section Two

Review of Literature

A review of all the literature pertinent to grass production and weather-yield relationships would be beyond the scope of this study. Reference is made to only theoretical work concerning the effects of weather and certain policy variables on crop yields.

Attempts to measure weather effects on crop yield have taken either of two lines of research. One might be called the "traditional regression approach" and the other the theoretical approach. One of the earliest studies using the traditional approach is that of Mattice (1931). Twelve different functions relating various weather measurements to state and regional average corn yields were estimated. The variables of no significance were eliminated by a stepwise regression analysis. A priori hypothesis was made about the relationship of the weather variables with corn yield. The results of the analysis were dependent entirely upon the data used. There was no empirical test of any theory. Stallings (1958) also followed the traditional approach using check plot data from various crop experiments at agricultural experiment stations. Data was taken on specified crop varieties, grown under constant conditions of soil

environment and cultural practices, where only weather was allowed to vary. Indexes were computed for the unexplained variation in crop yields from the experiments. The weather variables are not defined in this approach.

Edwards (1963) used a theoretical approach laying out a preliminary hypothesis of the variables influencing crop yields. A thorough description of the biological processes involved in plant growth is accomplished which suggests the variables to use and then a theory of the functional relationships is presented. The model then is applied to small grain data to make the empirical test of the theory. The conclusions of this study were that the theoretical model is superior to the "naive" models of the traditional approach.

Oury (1965) sets out a theory of weather effects on crop yields which reduces the weather effects to two variables, temperature and precipitation. Since water provides as well as transports nutrients to the areas of photosynthetic activity and since the flow of water is dependent on temperature, the priori hypothesis is that these are the basic two physical variables explaining growth. Because temperature and precipitation are inversely correlated, they are combined in an index following the work of de Martonne (1926) and Ångström (1936). The index then becomes inversely related to temperature and directly related to precipitation.

McConnen (1965) hypothesized that over time both grazing patterns and precipitation affect range grass yields. The study was based on experiments on range pastures using three levels of forage utilization. A logarithmic function of time was assumed for forage utilization

and annual precipitation was assumed to be the only weather variable influencing range grass production. The intercept of the logarithmic function was determined by the level of grazing.

The following publications have been selected for review on the basis of how applicable their information was to the optimizing problem of the present study.

Cotner and Jameson (1959) present a discussion on the importance of costs in selecting a method for controlling Pinyon-Juniper. This study was based only on control operations in Arizona. It dealt with costs of two methods: a) burning individual trees, and b) bulldozing. Upon analyzation of the data, it was determined that the size of trees, the number of trees per acre, and labor were the primary variables that determine costs. The authors also pointed out that there might be some secondary variables such as soil and terrain, affecting costs.

In conclusion, the authors were mainly concerned with the specific variables of trees per acre and tree height. The particular framework for predicting costs holds up only if the type of equipment studied is available plus information concerning the other variables pointed out above.

In 1963 Cotner (1963a) published "Controlling Pinyon-Juniper." This bulletin reports the scope of Pinyon-Juniper problems in Northern Arizona, the current status of control work, the methods of control used, and a procedure for predicting costs for the leading control methods (bulldozing, burning, and cabling).

Variables found to be of primary importance were tree heights, densities, and average tree sizes.

In conclusion, the author was mainly concerned with invasion stands, and as a result his prediction methods are applicable to sites with this particular characteristic.

Cotner (1963b) presents a discussion of a framework which makes it possible to determine where, when, and how resource improvements should be made, with economic decisions considered the most relevant variable. This framework includes: a) determination of physical benefits relationship, b) determination of improvement techniques and costs, c) discounting the physical benefits stream, d) selecting the right improvement techniques, and e) determination of economic feasibility.

Hand chopping, individual tree burning, bulldozing, and cabling were the four major control methods discussed in determining the improvement technique to be employed. It was shown that the feasibility of an individual technique varied from site to site, with cabling being the most proficient on large acreages of middle-age trees on relatively level terrains, and hand chopping being applicable on sites with low densities of small trees.

In selecting the optimum year for control, a comparison of rate of benefit increase, and the rate of cost increase is made. If the two are equal, an optimum has been reached. The optimum technique is therefore defined as the technique providing the highest net return over time. In conclusion, the author is mainly concerned with invasion stands of Pinyon-Juniper and determining the optimum time for initial control.

In 1964 Arnold, Jameson, and Reed (1964) published information

on forage values and use of Pinyon-Juniper woodlands in Arizona. Information includes: a) a discussion of the problems created by Pinyon-Juniper, b) various uses and products derived from these stands, c) extent, location, and stand characteristics, d) effects of tree increase on other plants, e) principle methods used to control Pinyon-Juniper, f) response of vegetation to tree control, and g) costs and resulting benefits of control.

In conclusion, the study shows that: a) the costs comparison of the different techniques show that chaining and cabling are the least expensive methods, b) to obtain the maximum benefits from these methods some follow-up treatment on the slash is required, and c) in areas of low densities of small trees it was found that individual eradication methods prove to be more efficient.

Computer Programs and Miscellaneous Tables

The computation of all the aridity indexes was accomplished by means of a program developed for the IBM 1620 digital computer. Dr. Bernard Oury at North Carolina State University developed the program and allowed its use in this study. The aridity index computations were greatly reduced because of Dr. Oury's valuable help.

The input for the program is the accumulative monthly precipitation and monthly mean temperatures. These may be combined in either the de Martonne or the Ångström aridity index. The indexes are grouped for any arrangement of months desired. Each month's index is weighted by its variance before being grouped.

The Markov chain computations were greatly aided with the help of a program developed for the IBM 1920 digital computer. This program

was developed by Dr. William R. Reilly at the University of Connecticut. The program computes the limiting vector and the limiting matrix. The transition matrix, P, can be raised to successively higher powers up to P^{99} for a 10 by 10 matrix. Also included for firm movement analysis is a provision to compute a transitional state matrix and the n-stage vector. The input for the program is the initial state vector and the transition matrix which can be estimated by least squares, maximum likelihood or quadratic programming.

More specific detail of actual program operations and calculations will be included with any report of weights for computing weather station "normals."

Table 2.e.1 Angstrom index "normals" used in estimating prediction model for grass production*

Model Area	Weather Station	Normal Index
Fillmore-Murray	Loa	92
	Beaver	221
	Milford	49
	Desert Range	67
	Lund	101
	Cove Fort	213
	Koosharem	117
	Benmore	64
	Elberta	134
	Eureka	186
	Black Rock	139
Cedar City-Caliente	Hite	45
	WahWah Ranch	91
	Modena	114
	Caliente	90
Sitgreaves-Ft. Apache	Pioche	160
	Cibecu	183
	Pinedale	211
	Show Low	125

Model Area	Weather Station	Normal Index
Monticello-Durango	Monticello	153
	Cortez	150
	Northdale	177
	Blanding	122
	La Sal	---

* Individual values shown were used as many times as there were nearby projects from which forage production estimates were obtained.

Table 2.e.2 Single chaining slope classification for Arizona-Nevada area*.

Code	Average bid cost	General Description of slope
1	1.58	Level
2	2.27	Gentle slope
3	3.24	Rolling
4	4.27	Rolling with gullies

* The different types of slope were ranked in accordance with the average cost associated with it for the particular area in question.

Table 2.e.3 Single chaining soil classification for Arizona-Nevada area*.

Code	Average bid cost	General Description of slope
1	1.25	Sandy loam
2	1.52	Limestone silt
3	1.61	Sandy clay
4	1.94	Clay silt
5	3.09	Clay loam
6	3.94	Sandy silt

* The different types of slope were ranked in accordance with the average cost associated with it for the particular area in question.

Table 2.e.4 Single chaining slope classification for Utah, Colorado, and New Mexico area*.

Code	Average bid cost	General description of slope
1	2.61	Level
2	3.15	Gentle
3	3.91	Gentle rolling
4	4.53	Rolling

* The different types of slope were ranked in accordance with the average cost associated with it for the particular area in question.

Table 2.e.5 Single chaining soil classification for Utah, Colorado, and New Mexico area*.

Code	Average bid cost	General description of slope
1	2.36	Clay loam
2	2.59	Sandy
3	3.98	Sandy loam
4	3.72	Sandy clay
5	3.83	Sandy clay loam
6	3.90	Silty loam

* The different types of slope were ranked in accordance with the average cost associated with it for the particular area in question.

Table 2.e.6 Slope classification for bulldozing*

Code	Average bid cost	General description of slope
1	4.34	Level
2	4.54	Gentle
3	5.89	Medium
4	10.58	Medium-steep
5	11.47	Rolling-steep

* The different types of slope were ranked in accordance with the average cost associated with it for the particular area in question.

Table 2.e.7 Soil classification for bulldozing*

Code	Average bid cost	General description of slope
1	2.63	Rocky-sand
2	3.28	Rocky
3	4.92	Sandy loam
4	4.07	Silty clay loam
5	5.70	Clay loam
6	7.64	Sandy

* The different types of slope were ranked in accordance with the average cost associated with it for the particular area in question.

Table 2.e.8 Slope classification for double chaining*

Code	Average bid cost	General description of slope
1	3.38	Level
2	4.33	Gentle
3	4.52	Rolling
4	5.60	Rolling with gullies

* The different types of slope were ranked in accordance with the average cost associated with it for the particular area in question.

Table 2.e.9 Soil classification for double chaining*

Code	Average bid cost	General description of slope
1	3.65	Silty loam
2	3.91	Medium loam
3	4.44	Sandy clay
4	4.73	Sandy loam
5	4.75	Sandy clay
6	7.00	Sandy

* The different types of slope were ranked in accordance with the average cost associated with it for the particular area in question.

Table 2.e.10 The analysis of variance for mean kills of the three eradication techniques*

Source of Variation	Degrees of freedom	Sums of squares	Mean squares	F
Total	108	2.6653		
Treatment	2	.3832	.19159	8.899**
Error	106	2.2821	.02153	

** Denotes significance at the .01 probability level.

* The hypothesis tested was $H_o : U_1 = U_2 = U_3$ due to the results of the "F" test this hypothesis was rejected. This led to the acceptance of the alternative hypothesis $H_a : U_1 \neq U_2 \neq U_3$.

Table 2.e.11 The treatment mean kills for the techniques used in the study*

Treatment	Number of observations	Treatment mean
Single chaining	39	.7400
Dozing	47	.8309
Double chaining	23	.8965

* Data summarized from office reports.

Table 2.e.12 Production and crown canopy for three provinces

Coronado			LaSal			Escalante		
Plot No.	Production (in lbs.)	Crown Canopy (%)	Plot No.	Production (in lbs.)	Crown Canopy (%)	Plot No.	Production (in lbs.)	Crown Canopy (%)
383	72	.273	337	257	.103	279	46	.227
317	29	.373	341	38	.357	266	32	.283
311	82	.177	342	49	.387	260	39	.200
315	25	.333	343	79	.260	259	24	.280
313	62	.207	406	68	.380	276	101	.057
314	67	.267	391	57	.320	268	26	.223
360	76	.263	301	31	.397	379	4	.527
362	53	.303	293	34	.330	205	38	.257
366	54	.237	296	80	.273	208	36	.257
398	83	.180	300	104	.283	118	30	.380
399	93	.173	322	42	.410	119	28	.273
403	55	.270	323	28	.437	107	46	.190
26	119	.067	324	45	.350	108	15	.313
382	79	.223	348	41	.397	95	128	.083
288	100	.073	143	153	.140	104	29	.210
364	40	.270	46	117	.267	81	37	.203
384	34	.360	48	46	.370	114	61	.173
18	158	.030	151	25	.527	116	93	.153
			37	29	.543			
			193	21	.437			

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3. VALUING PINYON-JUNIPER ALTERNATIVES

3.a. Introduction to Product Potentials

The main current uses for pinyon and juniper products are for firewood, fence posts, Christmas trees, nuts, and a few mine props or ties. In any given year the aggregate retail value of the portion of these products harvested from BLM lands would be on the order of 305 thousand dollars (table 3.a.1.). Actual receipts accruing to BLM from pinyon-juniper sales in Colorado, Arizona, Nevada, New Mexico, and Utah average under \$40,000 per year (table 3.a.2.).

Table 3.a.1. Estimate of the annual retail value of pinyon-juniper products reported harvested from public lands*

Species or harvest area**	Average numbers reported	Product	Estimated retail price	Estimated value	Estimated value including free use
All species	30,000	Christmas trees	@ \$4.50	\$135,000	?
Pine nuts	500lbs.	Nuts	@ \$1.00	500	?
P.W.	200	Wildlings	@ .75	150	plus 37%
Pinyon	0	Saw timber	?	0	?
Juniper	0	Saw timber	?	0	?
5 states	85,000	Posts	@ .85	72,225	plus 45.7%
5 states	1,900	Cords	@ 27.00	51,300	
TOTAL				\$259,175	\$304.875

* Exclusive of the value of products stolen.

** Reports of timber disposition by species do not specify individual products other than saw timber. Therefore, reported post and cordwood disposition in Arizona, Colorado, New Mexico, and Utah are assumed to be entirely made from the pinyon-juniper type. This assumption is somewhat balanced by ignoring any timber product sales in Oregon or Idaho (some portions of which could be from the pinyon-juniper type). Similarly, Christmas tree sales include some species other than pinyon, but this should not be a large number.

Source: Tables 67, 73 and 74, 80 in 1962-63 and 1964-65: Public Land Statistics, USDI, Bureau of Land Management and Table 3.a.2 below.

Table 3.a.2. Reported annual returns to BLM from sales of pinyon-juniper products (largely)

	1962		1963		1964		1965	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
<u>Sales of Non-Timber Products on Public Lands</u>								
Christmas trees (baled)	790	\$ 571.50	763	\$ 257.80	700	\$ 420.00	250	\$ 150.00
Christmas trees (each)	237,924	25,219.87	85,454	24,601.95	32,935	20,295.78	28,577	16,335.15
Pinyon pine nuts (lbs.)					500	25.00		
Pinyon wildlings (each)	1,170	441.00	217	103.50	624	486.50	142	100.40
Juniper boughs							10,000	200.00
<u>Timber Disposition by Species (inc. free use)</u>								
Green (cords)								
Juniper saw timber	0		0		3.0		0	
Juniper other	1,443.3	\$18,885.07	1,878.8	\$30,673.56	1,204.2	\$22,549.73	1,252.4	\$15,612.11
Pinyon saw timber	0		0		0		6.4	
Pinyon other	48.2	207.00	42.9	103.00	2,613.0	5,236.00	102.0	382.46
Salvage (cords)								
Juniper other	554.7	1,529.50	374.5	601.90	18.5	56.90	17.2	186.00
Pinyon other	40.5	61.70	3,115.4	6,329.50	1,771.4	4,254.10	2,504.0	6,006.30
Sub-total		\$46,915.64		\$62,671.21		\$53,324.01		\$38,972.42
<u>Free Use Timber by Species (subtract)</u>								
	J	P	J	P	J	P	J	P
Cords	875	1,506	1,282	2,805	800.5	6,528	1,321	2,834
Posts	42,512	0	88,443	4,175	37,180	0	24,130	0
Poles	0	0	100	0	60	0	0	0
Other	0	0	0	0	3.3	0	0	0
MBF	.1	0	18.2	.3	0	0	0	0
Subtract Value	6,141.03	1,449.25	12,135.65	3,829.23	5,449.50	7,278.00	4,262.15	3,474 80
Total Net BLM Receipts		\$39,325.36		\$46,706.33		\$40,596.51		\$31,235.47

Source: Public Land Statistics, USDI, BLM, 1962, tables 74, 78, 69; 1963, tables 77, 69, 74; 1964, tables 81, 85, 76; 1965, tables 81, 76, 85.

While there is little reason to expect significant reductions in product harvesting in the immediate future, the long-run prospects are only middling. All indications point to an ever diminishing market for fence posts and it has been asserted that the general quality of pinyon Christmas trees declines from year to year (2, p.19). The Indian people have a special interest in pine nut harvesting, often from other than BLM lands. Only one mill was found to be sawing pinyon (cut from a national forest) on a regular basis. The owner also produced lump charcoal in crude kilns. Pinyon fireplace wood is an attractive product. In those locations where costs and markets are compatible, sales should increase.

Other potential products have been suggested at various times: paper pulp, wood molasses, chipboard, resin, essential oils or charcoal. Of these, only charcoaling the trees appears to offer any immediate prospects. Pulping pinyon or juniper apparently results in a somewhat technologically inferior end product, but a more important drawback is the necessarily greater expense to process such crooked or scrubby trees (6, p.1;7). Wood molasses cannot yet be produced at a cost that compares with feed supplements such as beet pulp, silage or cotton seed meal (12). The same conclusion may be reached with respect to pinyon resins (1, p.vii-viii) No data is yet available concerning the extraction possibilities and worth of the essential oils obtainable from juniper.¹ The notion of manufacturing chipboard from pinyon-juniper has received attention from tribal councils and at least one Forest Service Experiment Station. Some experimental panels are

¹Current research of Prof. W. H. Johnson, Dept. of Forest Service, Utah State University should provide this information.

reported to have been made, but no technical or cost data have been obtained in the course of the present study (11, 1965, p.11).

With respect to all potential products the opinion may be hazarded that high unit costs of harvesting pinyon-juniper relative to the wood volumes obtained constitute a major barrier to introduction of new technological uses for the woodlands in question. Unless some huge, self propelled machine can be devised to harvest large acreages economically, the only way to obtain the raw materials is to fell trees individually. Where selectivity is a necessary factor (e.g. fence posts), it may be impossible to avoid hand work. Even in the case of charcoal production, the most recent feasibility study assumes reliance upon portable kilns to hold harvesting/transport costs within bounds (3).¹

The total economic worth of pinyon-juniper woodlands to either the Bureau of Land Management or to all of society cannot be ascertained in the absence of a woodland product inventory. Since the ecological phase of the present study was not designed to supply such information, product valuations for management purposes must be expressed in terms of convenient measuring units, such as merchantable posts per acre, or truck loads of firewood, etc. In practice, actual estimates of product numbers must be used in any evaluation of alternatives. Still, some notion of potential results can be obtained by analyzing

¹In this instance, casual observation suggests that the finished product is attractive and that it possibly could be sold. Thus, from here on success is mostly a question of marketing, promotional and organizational technique. For this reason an effort has been made to appraise management potentials with respect to charcoal, just as in the cases of the more traditional products.

examples where product yields per acre are based upon empirical findings. Table 3a3 is a listing of realistic assumptions that shall constitute the fundamental ecological data to be used in estimating (in succeeding sections) ranges of certain product values per acre.

Table 3.a.3. Woodland stand characteristics assumed for purposes of estimating rotation benefits

Ecological province	Site index	Species	Av. tree height dominant stand	Av. crown dis. dominant stand	Crown cover	
					Percent	Percent
Escalante-Sevier	21-31'	P	28	15.5	15	35
		J	24			
	11-20'	P	16	10.0	15	35
		J	13			
LaSal	21-31'	P	32	17.5	15	35
		J	27			
	11-20'	P	18	11.5	15	35
		J	14			
Colorado	21-31'	P	37	19.5	5	25
		J	32			
	11-20'	P	20	13.0	5	25
		J	15			

Source: Figures 4.c.1., 4.c.3. of Part A; average tree heights assumed from field experience; crown cover percentages chosen to provide a range of extremes matching data requirements of (8, pp.6-7).

It may be thought this conclusion proves that an important aspect of the "failure" to exploit pinyon-juniper woodland resources hinges upon a lack of imaginative enterprise. Probably there is some truth in this notion; e.g., once the technological and commercial possibilities of combining charcoal and essential oil harvesting operations are better understood, increased utilization may occur. As of the present,

however, the overwhelming economic fact is that opportunities exist mainly in forms that are attractive to certain groups or individuals that, by virtue of their present geographic location, or due to lack of alternatives, are willing to capitalize on them (5, p.7).

Concerning valuation, it has seemed best to treat the agency prices charged as a general reflection of minimum social values of the "intermediate" products in question. This certainly is proper wherever bidding is employed and in many instances of negotiation. On the other hand, the assumption is too crude to apply to annual fee charges levied on range users.¹ In such cases, appropriate adjustments must be included in the assumed valuations.

Having made choices which establish base values it is possible, by adding transport and harvesting costs, to make judgments about the ranges of apparent private profits from retailing pinyon-juniper products. Since any variations in transport costs among unprocessed pinyon-juniper products are largely due to differences in bulk (given the same hauling equipment) it is convenient to introduce in Tables 3.a.4, 5, 6, those transport assumptions which will be common to all products considered.

The travel times shown in Table 3.a.4 are for open, rural highways with average daily traffic under 4,800. Line haul conditions are assumed to preclude more than 2 speed changes per mile. Any time speed changes rise above 3 per mile, significantly more fuel is consumed and the values in table 5 should be used to correct assumption estimates. Speed changes are due not only to off-highway conditions,

¹Cf., (9, table #4)

Table 3.a.4. Estimated variable costs per vehicle mile for rural line hauls

	Truck Size			
	Gas 2½ ton	Gas-Semi		Diesel-Semi 72,000 GVW
		Small 36-42,000 GVW	Large 68-70,000 GVW	
Fuel				
Gal./mi.	.228-.30	.299	.324	.204
Cost/mi. ¢	.0638-.084	.0837	.0907	.051
Oil				
Cost/mi. ¢	.0019	.0022	.0024	.0031
Tires	.0155	.0200-.0238	.0238-.0250	.0238-.0250
Repairs & Maint.	.0141	.0206	.0285	.0299
Av. Variable Cost/¢	.0953-.1149	.1265-.1339	.1454-.1466	.1078-.1090
Travel Time/Mile	--	1.615	1.492	1.512

Source: (4 and 10).

Table 3.a.5. Increased fuel consumption per mile due to varying average daily traffic levels and speed changes

	<u>ADT</u>	<u>ADT</u>
2 lane	11,000	17,000
4 lane uncontrolled access	36,000	55,000
4 lane controlled access	75,000	90,000
Speed Changes/Mile	3	4
Increase (gallons)		
GVW 30,000	.017	.03
GVW 68,000-70,000	.04 Gas	.09 Gas
GVW 72,000	.03 Diesel	.065 Diesel

Source: (4, tables 11, 13 and figure 9).

Table 3.a.6. Estimated fixed vehicle costs for various truck sizes (Utah)

	Truck Size		
	Gas 2½ ton	Gas-Semi 36-42,000 GVW	Diesel- Semi
Original investment	7,000	11,000	30,000
Annual depreciation	700	1,100	3,000
Interest on capital @ 8%	560	880	2,400
Insurance	250	400	950
Taxes (Utah)	125	200	350
Licenses (Utah)	<u>180</u>	<u>200</u>	<u>460</u>
Annual total fixed cost	1,815	2,780	7,160
Estimated annual mileage	23,000	48,000	85,000
Approx. annual cost/mile	7.98¢	5.79¢	8.42¢

Source: Adapted from (10, table 3 and figure 2).

adverse traffic levels have the same consequences. Thus, if traffic volumes and operating conditions are expected to fall into the ranges shown in table 5, the indicated fuel adjustments should be made.

The fixed costs presented in table 6 are useful mainly as a check upon truckers' personal estimates of cost per mile for they reveal whether an allowance is being made for such costs. In practice, individual truckers probably base most of their day-to-day operating decisions upon expected variable costs similar to those presented in Table 3.a.4. This is the method employed in most of the examples to follow.¹ These examples combine variable transport costs with appropriate harvesting costs, and agency stumpage or permit charges.

¹In the case of each product, wherever an allowance for fixed costs is included in any transport cost estimates, the step will be clearly noted.

The base values or agency charges, when associated with per acre yields, also determine the extent of future product returns which must be foregone if the trees are removed and replaced by grasses. But not all product sales must be foregone if conversion is undertaken. Much depends on whether product rotation is economically justified in the first place or whether the products can be salvaged for sale following control. While it is true that in any particular instance land managers should perform separate calculations of net benefit potentials expected from alternative sources of action, some rough "rules of thumb" can be obtained by arbitrarily varying per acre product yields in the face of expected benefits from typical conversion operations. This procedure treats questions of watershed and big game values as issues requiring side calculations to be introduced after more easily measured monetary gains and losses have been evaluated.

In each of the sections to follow, a consideration of private benefits from utilization of the products in question precedes discussion of management potentials.

No allowance is made for an increase in agency costs due to more intensive management, e.g., Christmas tree rotation.

Production of many products is complimentary for all practical purposes; harvesting will not interfere with current grazing intensities. This is true whether or not tree rotation is feasible. The assumptions concerning management complementarity that have been adopted throughout are shown in Table 3.a.7. All the cells marked with "N" mean that fostering, production of the products or uses in question can be accomplished simultaneously; management programs for one need have little effect

on the other. Cells marked with "Y" mean that management for one use effectively removes from further consideration the alternative use. "Y-N" indicates that uses will not be competitive if selective harvesting is practiced; charcoal production need not hurt post sales if posts are cut separately or removal of dead trees need not interfere with pine nut production, etc. "N*" indicates that both products will continue to "exist" but one might be partly damaged or be much more difficult to harvest, especially if tree slash is windrowed. The only product for which tree rotation is considered is Christmas trees.

Table 3.a.7. Woodland use competition⁺

	Exist- ing grazing	Christ- mas trees	Posts	Pinyon fireplace wood	Pine- nuts	Charcoal	Con- version
Existing grazing	-	N	N	N	N	N	N
Christmas trees	N	-	N	N	N	N	Y-N
Juniper posts	N	N	-	N	N	Y-N	N*
Fireplace wood	N	N	N	-	Y-N	Y	N*
Pinenuts	N	N	N	Y-N	-	Y	Y
Charcoal	N	N	Y-N	Y	Y	-	N*
Conversion	N	Y	N*	N*	Y	N*	-

+ Tree rotation periods with time horizons greater than 50-60 years are excluded.

* Some harvest loss if very tangled or broken; windrowing may prevent post cutting entirely.

N=Competitive

Y=Mutually exclusive

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3.b. Christmas Trees

Market for Pinyon-Christmas Trees - As recently as 1962, consumption of pinyon pine accounted for 1 percent or about 430,000 out of total United States Christmas tree sales. Possibly as many as one-half of these were of the species *monophyllia*, cut mainly in Nevada and Utah. And the sales of about 100,000 trees or 25 percent of all pinyon were concentrated in the Salt Lake City-Ogden-Provo market. Relatively few trees of the species *edulis* were among the 100,000. Most of the remaining *monophyllia* trees cut in the Great Basin went to Las Vegas or were shipped to California from ranger districts in Western Nevada. Sales of 150,000 to 200,000 *edulis* trees were scattered throughout the remainder of the West.

In any given year some two-needle pinyon appear in the Denver market and others are shipped to Phoenix or Albuquerque from the Four-Corners area and western New Mexico.¹ Little commercial cutting is allowed from the national forests nearest Phoenix due to a great demand for individual pinyon permits. Presumably a substantial number of pinyon are marketed in New Mexico, but commercial cutting from BLM districts included in the study area do not appear to be very significant. In fact, current sales of Christmas trees from BLM lands are concentrated in Nevada.

From the standpoint of the ecological provinces included in the present study, the Salt Lake City market currently is the most important outlet for BLM pinyon Christmas trees.

¹In 1963, about 15 percent of 350,000 Christmas trees cut in New Mexico were pinyon pine (1, p.15).

In recent years a number of studies have been made of the demand for Christmas trees in this particular market (2, 3, 4, 5, 6, 7). The results suggest that pinyon sales are falling off in both absolute and relative terms. From the collected information it is possible to detect two important trends that are contributing to this decline. First, there has been a general increase in the use of artificial trees. Over 46,000 Utah families no longer use natural trees, a ten fold increase since 1960 (3, p.23). As a consequence, there is some question whether the rate of household formation can add enough market demand for natural trees to offset switching to artificial trees (3, p.23). Secondly, there has been an "obvious decrease in [pinyon] quality" (2, p.19).

The same market studies indicate the volatile nature of the supply of Christmas tree species from year to year (table 3.b.1). Retailers go in and out of business according to their most recent year's experience. In a bad year, 12-15 percent of trees reaching Salt Lake markets are unsold, whereas demand matches supply within 1-2 percent in a profitable year. Good profits then induce a glut of trees in the following holiday season. Sometimes weather or other conditions can upset supply patterns. Some of this uncertainty and harvesting difficulty can be avoided by developing tree plantations. This is a trend that is emerging in intermountain markets. But pinyon species are outside this trend. All recommended plantation stocking species exhibit minimum rotation periods 4 to 7 times shorter than pinyon growing under natural conditions (4, p.6-10).

The high range of wholesale prices shown for pinyon (table 3.b.2) during recent years is a reflection of the shortage of high quality

Table 3.b.1. Species of Christmas trees in Utah retail yards. Various years (percent)

	1952	1953	1960	1961	1963	1965
Pinyon pine	20	48	43.7	38.2	29.7	25.6
Douglas-fir			35.4	35.0	30.7	19.1
Subalpine, Balsam, and fir	70		4.4	10.7	20.7	25.3
White fir			7.2	2.1	1.9	11.7
Ponderosa pine			2.0	2.1	5.6	4.3
Hodapple pine			1.8	2.7	1.9	2.4
Spruce			5.4	9.1	9.3	11.0
Scotch pine			--	--	0.2	0.6
Others			.1	.1	--	--

Source: (2, 3, 4, 5, 5) and unpublished records of Forest Science Dept., U.S.U.

Table 3.b.2. Wholesale and retail price ranges for pinyon pine on the Salt Lake City market (selected years)

	Wholesale			Retail		
	Low	Avg.	High	Low	Avg.	High
1960	1.75	2.00	2.50	2.00	4.00	6.50
1961	--	2.00	--	--	4.25	--
1963	--	2.25	5.00	2.00	--	8.00
1964	--	--	--	--	4.00	--
1965	.85	--	5.00	2.00	--	9.00

Source: (2, 3, 4, 5, 6) and interviews with Christmas tree cutters.

trees. Stumpage prices for both the Forest Service and the BLM have averaged very near 50¢ per tree in areas where monophyllia are cut. An upward trend toward 60¢ in the most recent years is indicated by the prices shown in table 3.b.3. The Forest Service is able to charge 50¢ per tree for edulis in the northern Arizona area, but 30¢ is a more usual upper limit for this species.

Table 3.b.3. Examples of pinyon prices, cut and on stump, by agency and location (various years)

Year	Cut trees			On Stump			Agency
	Location	Number+	Price	Location	Number+	Price	
1958				Fredonia	100	25¢	F.S.
1958				Austin	500	50¢	F.S.
1959				Lamoille	700	50¢	F.S.
1960				Brigham City	--	58¢	BLM
1960				Kanab	650	35¢*	BLM
1960				Cedar City	4,540	46¢-76¢	BLM
1960				Fredonia	1,400	50¢	F.S.
1961	Ely	2,000	1.25	Austin	590	50¢	F.S.
1961				Fredonia	150	50¢	F.S.
1962				Fredonia	300	50¢	F.S.
1962				Ely	4,000	10¢/bd.ft.	F.S.
1963				Vernal	650	*	F.S.
1963				Grand Canyon	--	25¢	F.S.
1963				Magdaleno	--	25¢	F.S.
1963	Ely	?	1.60	Ely	4,800	55¢-65¢	BLM
1963				West Nevada	--	75¢	F.S.
1963				Carson City	200	55¢	BLM
1963				Albuquerque	100	25¢	BLM
1963				Monticello	--	28¢	BLM

+ Tree numbers are shown only to suggest the sample size, they do not indicate total area sales.

* Edulis

Source: Agency records and interviews with Christmas tree cutters.

The names of some sixty cutters who bid on pinyon tracts were obtained from various sources. Most of these resided in Nevada, Utah, or Arizona. Nevada cutting operations of several such groups were observed during November 1964. The cost and return data obtained have been used to estimate the apparent profitability of Christmas tree harvesting. Only cutters working BLM lands were contacted and these worked mainly in the Ely district.

Private Cost and Returns from Harvesting Nevada Monophyllia Trees for the Utah Market - Physical organization of cutting operations vary from one or two men with a pick-up who live only a short distance from the sale tract to the use of crawler tractors to pull flat, low trailers right into tree felling areas. The biggest cutters in terms of tree numbers are headquartered in Utah and they caravan to locations adjacent to the Nevada or Utah sale tracts with living quarters, a truck large enough to carry 300 trees per trip to Salt Lake-Ogden, one or more pick-ups and at least one four wheel drive vehicle to carry trees from the mountain to the stacking area. Much of the labor is not hired for day wages, for the cutting is carried out on a partnership or donated basis (Boy Scout-Church groups). Where labor is hired the rate is about \$10 per day plus food and camping quarters. One man can cut 50 trees in two hours if the cutting is "good", but the ordinary rate is 50 trees per day. Gasoline costs range from 28¢-36¢ per gallon depending on quantity purchased.

In the following examples (tables 3.b.4, 3.b.5, 3.b.6, 3.b.7) the costs of camping quarters, depreciation of equipment, and interest on capital have been ignored. Where indicated, some allowances have

Table 3.b.4. Estimated costs and returns to harvesters of Nevada
Monophyllia delivering to Utah markets

I. Minimum costs of 4 man operation (assuming that one man can pick up and haul all trees)	
Transport	
Round trip, 2½ ton gas Bobtail, 530 miles @ .0947¢	
cost/tree (300 tree load)	.1673¢
4X4 30 miles @ 10¢	
cost/tree (60 tree load)	.05¢
Labor	
3 hired men @ 13.00/day, 50 trees each, 2 days	
per 300 tree load	
cost/tree	.26¢
Stumpage	.60¢
Total cost/tree delivered Salt Lake market	
(no allowance for manager's time or incidental costs)	\$1.077
Wholesale price received/tree	\$2.25
"Apparent" gain/tree	\$1.17
II. Minimum costs of 4 man operation (assuming two men pick up and haul trees)	
Labor cost/tree	.39
"Apparent" gain/tree	\$1.04
III. Manager's net receipts at \$1.04/tree	\$312.00
3½ days personal labor @ \$30/day	\$105.00
"Apparent" gross profit per load	\$207.00

Table 3.b.5. Estimated returns to truckers purchasing cut Christmas trees
for main BLM market

I. Minimum variable costs and returns exclusive of two days driver time or lodging/tree (42,000 GVW Semi)	
Cost of cut trees	\$ 1.60
Cost of transport (approx.)	.15
Total cost in Salt Lake Market	\$ 1.75
Wholesale price	2.25
Apparent gain/tree	.50
Apparent gain/load (420 tree load)	\$210.00
II. Minimum costs allowing 16 hours of labor cost at \$3.00/hr. plus \$10 lodging and food costs	
"Apparent" gain/load	\$152.00

Table 3.b.6. Effect upon gross returns of 300 tree loads sold directly in retail Christmas tree markets

I. Load sold @ \$4.00/tree (no culls)		
Gross receipts		\$1,200.00
Harvesting costs		323.10
Apparent gain (exclusive of manager's time during harvest and all selling expenses)		876.90
II. Gains for small harvester - retailers (2 truck loads, cull trees - 16%)		
Gross sales		\$2,000.00
Harvesting costs	\$646.20	
Rent of sales lot	75.00	
Sale license	25.00	
		746.20
Apparent gain (exclusive of seven days personal harvesting labor, selling effort and expenses, depreciation and interest on equipment and capital)		1,253.80

Table 3.b.7. Example of costs and returns from harvesting and retailing pinyon Christmas trees with donated labor (church-scout groups)

Labor and equipment		
25 persons, cutting time 1½ days, total time 3 days; 2 ton, 1½ ton, 2 pick-ups, ¾ ton 4X4 camping trailers		\$ 420
Stumpage for approximately 700 trees		
gasoline cost		155
oil, tires, & maintenance		donated
food and lodging		donated
labor		donated
selling costs		donated
Gross receipts from sales averaging 3.50/tree (10% cull)		2,205
"Apparent" gain (75 man days effort)		\$1,630

been made for wages of the person managing the operation. Emphasis is upon out-of-pocket costs and therefore private returns are put in the most favorable light possible.

Management Potentials for Pinyon Christmas Trees - BLM receipts of \$165-195 per 300 tree load are meaningless for management guides unless they can be converted to per acre revenues. But this is a difficult task. A given tract may be covered with pinyon yet not contain any merchantable trees. Cutters with high standards claim that exceptional cutting in Utah or Nevada would be in areas yielding 30-40 trees per acre. Cutters have also claimed that as few as 200 trees have been taken from tracts covering 5-7 sections. A common claim is that "good" cutting will yield 1,000 high-grade trees from two sections. Good trees are often found in groups, so the entire tract area might not be cruised, still the acreages involved explain why cutters working steadily on favorable tracts only average about 10 trees per hour. On such tracts an efficient four-man team will average 75 trees per day each.

Casual reading of descriptions of sale tracts put up for bid suggest that areas are "managed" in fairly large parcels, e.g., over one-half section in size. Heavily stocked portions consisting of a few acres randomly scattered throughout tract are not broken out for separate treatment. At a high-grade tree rate of 75¢ each, pockets of trees containing 40 well formed trees per acre might yield \$30 in stumpage but the average per acre yield for the whole tract would only be 75¢ to \$1.50.

All this leads to a consideration of rotation analogous to that employed on some tree plantations. If the initial cut takes all merchantable trees, the remaining well-shaped trees in the 3-4 foot class might be viewed as a new even-age stand of seedlings.

It is also possible to think of rotation in the sense of cutting only "additional" growth so that initial stand conditions can be maintained through time. This latter view implies the existence of unevenage stands so that current growth rates can be used to "project" the tree numbers rising through the various height classes during any convenient rotation period. This in turn requires that tree numbers per acre be great enough to talk meaningfully in terms of ".33" or "3.19" "new" trees per height class. Since partial trees cannot be harvested, it is technologically impossible to cut to achieve a sustained yield which will maintain existing stand conditions, if stocking rates are in fact as low as 1 or 2 saleable trees per acre. This latter view of "rotation" is therefore probably not operational. Given the average pinyon situation the best concept of rotation is to sustain yields at new stocking levels established as a result of initial cuts.¹

If, as a policy, all existing saleable trees are cut, questions concerning rotation are limited to the determination of the most profitable time period. Supposing an initial cut would leave all 4' and under

¹It should be noted that even if stands of 20-40 saleable trees per acre could be managed independently, it is almost certain that the BLM will net greater money returns through a policy of immediate liquidation of all saleable trees. The amount realized will almost certainly exceed the present value of future sales of the projected growth increment proposed to be harvested at 10 or 20 year intervals, even if the time horizon is infinite and discount rates are very low (7, p.7). If all merchantable trees are immediately harvested, the rotation pattern that subsequently could be followed would be completely analogous to the 1-2 tree per acre situation.

trees, it would take 12, 18, and 25 years for growth to reach 6, 7, and 8 feet respectively (Part A, 9.6). Rotation periods shorter than 15-20 years will not satisfy the most discriminating cutters.

Whether 15 or 20 will be more advantageous to the selling agency depends on estimates of the effect tree harvesting size will have upon future real stumpage prices likely to be received. If it is likely that good 8-9 foot trees will invite 75¢ bids in real terms (20 year rotation), whereas 6-7 foot trees will net 55¢ (15 year rotation), the time period which will yield maximum returns to the BLM can be determined by inspection, once some simple calculations have been completed.¹ It happens that for the values mentioned it would be best to choose the longer period (table 3.b.8). The present value per acre would be 75¢ plus 89½¢ for a 15 year rotation compared with 75¢ plus 93¢ for a 20 year rotation (3% interest). As discount rates are reduced the longer period increases in relative desirability. However, the interest rate only needs to be increased to 5% in order

Table 3.b.8. Present value of perpetual stream of receipts from one tree per acre under two rotation periods (various discount rates: $i = .075, .050$; $t = 20, 15$)

r	t	Value of				
		initial cost	1%	2%	3%	5%
75¢	20	75¢	\$3.105	1.445	.931	.454
50¢	15	75¢	\$3.409	1.543	.896	.463

¹For each rotation solve: $Vo = r / [(1+i)^t - 1]$

Where: Vo = present value; r = recurring returns; t = number of years between periodic recurrances of r .

to swing the balance in favor of 15 years. More importantly the estimate of effects on unit receipts (in real terms) due to choice of the shorter period are crucial. If "smaller" trees can still command prices near those of "taller" trees, i.e., if they are expected to sell at "average" prices, the shorter the rotation period the better.

These general results will hold for any multiple of 1 tree that might be expected to be left following an initial cut. Since managing woodlands for Christmas tree production does not appear to be incompatible with existing grazing or production of any other pinyon-juniper wood product (except in the very long run--over 150-200 years for firewood and 80-90 for pinenuts), the only additional factor needed for a management decision is the net monetary effect of converting "Christmas tree areas" to adapted grass species.

In general, any benefits from conversion must be large enough to off-set losses from potential product sales. Estimates of control gains must be made by employing models similar to those described earlier, by relying upon past experience, or by employing any other acceptable method.

Suppose an Ely District area containing "some" Christmas trees is investigated for conversion benefits and the optimum technique is to chain, windrow, and drill. Then, assuming average historical figures for Escalante-Sevier province projects (increase in annual net AUM values per acre of \$1.46; force account costs of \$9.35 per acre or contract costs of \$18.35 per acre; forage life of 40 years' discount rate of 5%) the present value of converting a "good site" (i.e., high percent pinyon; Part A, p.202) would be \$15.70 and \$6.70 for force account and contract jobs respectively.

Assuming 55¢ stumpage in real terms could be expected from future pinyon Christmas tree sales on a 15 year rotation basis, the site would have to support a saleable growing stock per acre of 16 trees to equal present values of a force account job and 7 saleable trees per acre in the case of higher contract costs. This assumes the initial cut is salvaged prior to chaining. Using these not atypical figures, 4,500 - 10,200 saleable trees per section would have to exist before present values would equal those offered from conversion (table 3.b.9).

The calculations of conversion benefits make an allowance for permit values not captured by existing fees. If only the direct grazing fee return to the BLM is considered, the "required" tree numbers should be reduced by a factor of 3. If the 33¢ fee can be thought to be a measure of social benefits, it is likely that the better viable Christmas tree sites are worth as much in their present state as if they were to be chained, windrowed and drilled (especially if the conversion is performed by contract; lower force account costs could be offset by about 5 trees per acre). Monophyllia lands with two or three good trees per acre almost certainly have a greater value than they would yield per acre if only a chain and broadcast technique were employed (assuming benefits to the BLM exclusive of uncaptured permit values).

All the above assumes the areas have never been cut over for Christmas trees. When chaining alternatives are evaluated with respect to monophyllia lands more or less recently cut over (Escalante-Sevier province), the required stocking rates are increased considerably. Assuming the same figures, 36 and 15 trees per acre would be required

Table 3.b.9. Number of saleable pinyon Christmas trees on un-cut Escalante-Sevier areas necessary to offset returns of various conversion treatments.

	Chain, Windrow and Drill								Chain and Broadcast			
	High returns				Low returns				Average returns			
Typical conversion results - no allowance for tree regrowth												
Value of net annual increase in AUM	1.45		1.45		.615		.615		.24		.24	
Cost/acre	9.35*		18.00		10.50*		16.00		5.05*		8.00	
Discount rates	4%	2%	4%	2%	4%	2%	4%	2%	4%	2%	4%	2%
Present values of conversion results using discount rates indicated	19.52	30.22	10.87	21.67	1.67	6.32	-3.83	.82	-.30	+1.51	-3.25	-1.44
Number of saleable trees required/acre***												
Expected stumpage rates- real terms (15.yr. rotation)												
.40	25	29	14	21	2	6	0	0.8	0	1.5	0	0
.50	20	23	11	17	1.5	5	0	0.6	0	1.1	0	0
.55	18	21	10	15	1.5	4.4	0	.5	0	1.0	0	0
.60	16	19	9	14	1.4	4.0	0	.5	0	.9	0	0
.65	15	18	8	13	1.2	3.7	0	.5	0	.9	0	0
.70	14	16.5	7.8	12	1.2	3.5	0	.45	0	.8	0	0
.75	13	15.5	7.2	11	1.1	3.2	0	.42	0	.75	0	0

* F.A. = Force Account

** No allowance made for future losses of pinenut sales, or for posts uncut prior to conversion. Net returns for increased AUM numbers valued at "social value" of \$.82/AUM for spring-fall ranges in Escalante-Sevier province (cf. 9, table 4). Tree rotation and forage returns both assumed to have lives of 40 years. No allowance for deferred grazing. Forage returns based upon typical 1964-1965 field observations.

*** If area has been "recently" cut over - the number of trees in each cell of the table must be slightly more than doubled. Solid zeros in the table mean that the conversions have negative present values at the discount rate tested, i.e., any positive number of Christmas trees are better than the treatment indicated. If AUMs are valued at 33¢ in real terms, the tree numbers above should be reduced by a factor of 3.

to offset returns from force account and contract conversion jobs respectively. Again these would be reduced by a factor of 3 if benefits are limited to grazing fee receipts.

Of course, Christmas tree potentials do not have to carry all the brunt of the comparisons. To the degree that future pinenut sales will be lost due to eradication, the absolute number of potential trees "needed" is reduced. Losses of potential post sales would have the same effect. In many cases, posts might be sold out of juniper slash but the stumpage might have to be reduced and some posts will be damaged and lost in the chaining process. Windrowing will greatly decrease any harvesting possibilities (even firewood). If posts or firewood are sold in advance they drop out of the management decision entirely (assuming no post or firewood rotation).

Obviously, the reliability of the above generalizations hinges upon the expected stumpage from the trees given the rotation period, and upon the best estimates of AUM gains and of their future value. Although the examples assume a 5% discount rate, relative comparisons won't be much altered by higher rates. More trees would be "needed" but this would be offset by lower present values of expected conversion benefits. Similarly time periods beyond 50-60 years, once interest rates are around 5 or 6 percent, will not have much effect on present values.

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3.c. Fence Posts

The Commercial Market for Juniper Fence Posts - Juniper posts are harvested from all BLM lands surveyed by the present study, but the exact size of the total cut is difficult to estimate. This is mainly due to the incidence of trespass and theft. And it is certain that district office sales records substantially understate the number of posts actually reaching commercial markets (table 3.c.1).¹ In fact, it is quite possible that 1/3 to 1/2 of all posts retailed are stolen.

In 1953, members of the Forest Management Department at Utah State University estimated total post use by all persons and agencies

¹An additional factor contributing to the difficulty of estimating retail posts sales is that many are cut on "free use" permits. It seems possible that some of these might enter commercial channels. In addition to recorded annual sales of 45-50,000 from Utah BLM lands about 20,000 posts are cut from national forests.

Table 3.c.1. Reported Disposition of posts from BLM areas in five states (various years)

State	1959		1962		1963		1964		1965	
	Total	Free Use	Total	Free Use	Total	Free Use	Total	Free Use	Total	Free Use
Arizona	9,950	7,330	9,752	9,185	12,598	9,248	12,835	10,275	5,623	4,946
Colorado	263	1,500	7,901	300	20,685	3,037	14,309	160	9,052	600
Nevada	34,351	29,251	26,357	4,382	49,285	1,216	32,528	9,284	23,125	9,268
New Mexico	61,652	11,510	5,836	9,694	38,968	28,982	9,007	770	8,883	2,507
Utah	52,754	200	59,975	9,845	70,692	40,790	61,577	13,980	49,159	2,110
Total apparent commercial sales	109,179		76,415		108,955		95,787		76,411	
Total value of apparent sales @ 15¢ ea.	\$16,376.85		\$11,462.25		\$16,343.25		\$14,368.05		\$11,461.65	

Source: Tables in Part 7, Public Land Statistics, Statistical Appendix to Annual Report, U.S.D.I., Bureau of Land Management, (Washington: G.P.O. 1959, 1962, 1963, 1964, 1965).

in Utah to be 2,186,265.¹ This value was generalized from the results of a 5 percent mail questionnaire, and appears greatly exaggerated (to be accurate, theft would have accounted for at least 80-90 percent of all posts cut). Even if it were assumed that half this number were consumed locally, at least 60 full-time trucker-peddlers would have been required to move the remainder. There is no evidence that trucking activity on such a scale ever existed.

The actual commercial sales and total cut figures must lie between "office figures" and the extreme mentioned.

Since post sales are more significant in Utah than in other sections of the five-state study area, a number of post truckers were contacted in an effort to make some estimates of the level of peddler activity. In turn, these were used to improve estimates of actual cut, not only for Utah, but for the entire study area.²

In addition to "free-use" applications, a significant number of posts are sold locally in Utah. The remainder are taken by truckers who peddle in Northern Utah, Southern Idaho, Southwestern Wyoming and Northwestern Colorado. If only the post haulers plying highways 89

¹Unpublished department mimeograph, n.d.

²As far as Utah is concerned it would require an assumption that individual truckers averaged only one load of 450 posts per month before it could be argued that theft was not a factor. But this is unrealistic for the maximum gross income per load would not exceed \$400 with costs of about \$195 for the posts alone (table 3.c.2). Even allowing for back hauls, monthly income would probably be too low for business survival.

The truckers referred to haul posts as a major part of their trucking operations. In addition they may haul poles as return loads from Montana or they haul alfalfa. Some Utah truckers have been peddling posts for over 20 years. They say that the number of competitors has fallen from over 20 to "about 10". The truckers which use rigs large enough to haul 20 to 25 tons (1,000 posts) say that they often haul only when they have firm orders.

and 91 are considered, it is easily possible that 110,000 posts move by truck each year (assuming 10 truckers making two trips of 475 posts per month).¹ Added to local sales, free-use, and some shipments from the Monticello area into Western Colorado, the total cut then would probably reach 140,000 posts per year. If agency sales are then subtracted, some notion of the amount of theft may be obtained.

If these estimates are at all accurate, it may be inferred that 50-55% of all posts come from private lands, state lands or are stolen from federal lands. Thus, yearly cut from BLM lands in Utah would be on the order of 90,000 - 100,000.

An attempt was made to cross-check Utah post "exports" by obtaining records from highway checking stations. But the truckers involved operate on annual licenses purchased from each of the adjacent states. Utah and Idaho only record actual cargo contents when interstate movements are made on the basis of trip permits. In Wyoming, even licensed truckers must report to checking stations, but records from only this state would be of little value since intermediate stops are often made in Idaho.

All this may seem unnecessarily speculative, but post haulers are reluctant to discuss a business that has conceivable links to trespass and is easy to enter. Contacts with post cutters provided little additional guide to the overall numbers involved. Most cutters who buy permits appear in agency records as small operators who pay stumpage

¹Some trips to Northern Utah are made in as little as two days. At other times, six or seven days are required to dispose of a load of posts. Large semi-trailers which can carry 20-25 tons or 1,000 posts are sometimes used.

on as few as 100-500 posts per year. They could hardly be expected to admit any theft. Only a few persons in Utah actually buy permits for 8,000 to 10,000 posts per year. Only one person was frequently mentioned as a "commercial" cutter in Eastern Nevada. These larger operators arrange to hire semi-itinerants or Indians to cut on such permits. Piece rates are reported to be 20-25¢ per post depending on whether chain saws are supplied. Large operators function essentially as suppliers of capital. Unless cutting operations could be observed over long periods of time, only fragmentary information can be obtained about market sizes.

Certain other persons also supply capital or at least ready markets for the output of actual cutters. Paying 30-35¢ apiece, these people accumulate posts in woodlots from which truckers are able to assemble their loads. In Utah, truckers pay woodlot operators 40-45¢ per post. If a given woodlot operator is a big enough buyer, presumably it is possible for him to exercise some price control.¹ In addition, once posts of various cutters are commingled in a woodlot, there is no easy way to be sure that all the stored posts are covered by permits.

It is possible to argue that the Utah experience is unrepresentative, and that wide-scale application of the rates suggested would be quite misleading. Nevertheless, actual cutting situations and personal contacts throughout the study region lead one to believe that all agency disposition figures could be increased by a minimum of one-third. This would mean that the annual market value of posts in the five-state area would be at least \$100,000 - \$115,000 per year.

¹Members of the field team were told, "If you want to truck posts on highway X, you have no choice but to deal with one source."

Table 3.c.2. Equipment, volumes, weights of alternative post loads, and post dimensions

	Truck size, type and weight			
	"Bobtail" or gas semi 36,000 GVW	gas semi 42,000 GVW	gas semi 72,000 GVW	Diesel semi 72,000 GVW
Variable operating cost/mile	12.5¢	13.3¢	15¢	11¢
No. of post/load	475	570	1,000	1,000
No. of cords	6.039	7.247	12.21	12.21
Cu. ft. per cord of posts			abt. 70	
No. of cu. ft./post			abt. .89	
No. of posts/cord			abt. 78.65	
A cord of split juniper weighs			abt. 2 ton	
Av. retail value in Utah-Nevada areas			85¢	

Apparent Profit Potentials for Post Truckers and Cutters - In table 3.c.3 are displayed the costs and returns of peddling in Southern Idaho various numbers of posts cut in Beaver, Utah under alternative conditions. These results are all based on the assumptions listed in table 3.c.2. Sometimes peddling a load takes as many as eight days. No costs for return trips are included since back hauls are common. No allowance has been made for fixed costs of vehicle operation (amortization of original cost, interest on capital, insurance, taxes, licenses, etc.). By making adjustments in the data shown, estimates may be made for other circumstances and locations. The variables difficult to estimate on a regional basis are the number of haulers involved in anyone area and the average number of loads carried per year. The best estimate for Utah seems to be 10-12 "full-time" truckers who average 2-3 loads per month, year round. The "profit" estimates shown can be improved on

Table 3.c.3. Effect of various assumptions upon apparent "profit" from hauling and peddling juniper posts

	GVW 36,000 475 posts	GVW 72,000 1,000 posts
Gross revenue/load	\$403.75	\$850.00
Woodlot cost/load	204.25	430.00
Net returns 300 miles		
3 day trip	148.50	360.00
5 day trip	138.50	350.00
7 day trip	128.50	340.00
Net returns 500 miles		
3 day trip	120.50	330.00
5 day trip	110.50	320.00
7 day trip	100.50	310.00
Returns/post 300 miles		
3 day trip	.312	.36
5 day trip	.291	.35
7 day trip	.270	.34
Returns/post 500 miles		
3 day trip	.253	.33
5 day trip	.232	.32
7 day trip	.211	.31
Out-of-pocket costs*		
Food and lodging	\$5/day	
Woodlot cost of posts	43¢ ea.	
Vehicle operating costs/mile:	36,000 (Gas) GVW 12¢	
	72,000 (Gas) GVW 15¢	
Retail selling price/post	85¢	

* All fixed costs of vehicle ownership and operation are ignored. Costs of empty backhauls are ignored.

an average of 25-30% if it is assured that peddlers organize their own post cutting and storing.

Some allowance is made for fixed vehicle costs in the estimates presented in table 3.c.4. These give some indication of the kind of incomes that might be earned under "excellent" post hauling circumstances: large

Table 3.c.4. Example of annual net income for post peddler under excellent conditions

Net sales		\$23,400.00
Expenses (tables 3.a.4 and 3.a.7)		
Variable operating costs	\$4,290.00	
Vehicle license*	367.50	
Interest on capital @ 8%	2,100.00	
Depreciation	2,625.00	
Insurance	675.00	
Property and use taxes	243.75	
Living costs	750.00	
		<u>11,051.25</u>
		<u>\$12,348.75</u>
Gross profit/post @ 85¢		23.75¢
Gross profit/post @ 75¢		13.75¢
Transport cost/post mile**		.027¢
Truck - 72,000 GVW Diesel semi	(orig. cost, \$35,000)	
Variable costs/mile	11¢	
Travel - 1,000 miles/week	(750 charged to posts)	
Selling price av.	85¢ ea.	
Post sales - 1,000/week	\$44,200	
Cost of posts @ 40¢ ea.	\$20,800	
Fixed costs	(Pro-rated according to post mileage)	

* Does not include license fees for operation in adjacent states.

** Transport cost/mile rises for short hauls, even though less expensive trucks are employed. For local hauls of 50-100 miles, the cost/post would be .1¢ to .16¢ higher.

diesel power truck, year round operation at one load per week plus advantageous post costs. Half the return trips are assumed to be empty and are charged against the post operation. It is clear that realization of large incomes mainly from hauling posts would require exceptional circumstances. If sales per week were to be 1/3 less the gross profit/post would fall to 17.95¢. Operating costs would rise

by \$2,000 per year if a gasoline rig were employed (lower depreciation and interest would offset this increase somewhat). More importantly, the selling price varies considerably depending on circumstances. Sometimes posts are sold for prices as low as 70-75¢. In such cases, profits per post may be virtually nil or even negative.

This possibility is illustrated even more clearly by the data in table 3.c.3. When it is recognized that fixed costs per post would be about 7-8¢ for the smaller truck and 4-5¢ for the larger, any combination of selling prices below 85¢ or costs above 40¢ would quickly eliminate trucker profits.

Thus far, attention has been concentrated upon post truckers and their profit potentials. But it must be recognized that except for local sales, the cutting and trucking operations are usually distinct. Thus, the cutter expects to make a profit also. It is possible that in the absence of alternative employment, individuals may cut posts "just for wages" and then cutters profit might be minimal. It all depends upon the wage rates assumed. At cutting rates of 50-60 posts per day, a person desiring to earn 1.50/hour would have to receive 25-30¢ per post plus any out-of-pocket costs for pick-up truck, chain saws, etc. If the posts are marketed locally in lots of 100 (at a further time investment of one-half day for delivery) an additional 7¢/post would be necessary to cover wages. Adding stumpage of 15¢ and operating costs associated with 10 gallons of gasoline plus chain saw maintenance would bring the total desired price to 42-48¢ per post. Local users pay anywhere from 50-70¢ per post in Utah so actual "wages" realized might rise somewhat above \$2/hour.

Since truckers often make up loads by collecting posts from concentration areas within woodlands and pay 40-45¢/post, cutters who pay stumpage can probably earn \$1.30 - \$2.00/hour where posts are of average density. If the cutter hauls the posts into a local sale yard he is unlikely to get more than 35¢/post because truckers still buy from the yard for 45¢/post and the yard owner wants a profit on each post. If the cutter accepts only 35¢/post (sometimes as little as 25¢), either he is willing to work for \$1.00 or less an hour or stumpage is not being paid.

In cases where a local sale yard owner purchases several thousand permits, Indians are sometimes invited to do the cutting and piling at 20-25¢/post. If permits cost 10-15¢, the yard owner can sell at 45¢ to truckers and still realize 5-10¢ per post. Again this is possible because the Indians are willing to work for the equivalent of \$1.00/hour or less.

All this suggests that cutting effort is expected to yield or earn about 10¢/post while an investment in hauling and peddling earns about 15¢. These rates of return appear to be achieved regularly in Utah by virtue of low wages or failure to pay stumpage. This means that if one wants to raise his hourly wage above \$1.40-1.50/hour it can only be done at the expense of the stumpage residual. At \$2.30/hour there would be no residual for stumpage. Since there is no way to avoid the transport and equipment costs, and since the market price is set by competition from substitute products, and since there seems to be an accepted profit level that can be maintained by virtue of the institutional arrangement that surrounds post harvesting, the

only source of higher returns to cutting is through avoidance of stumpage payments.

From the standpoint of the agency selling post cutting permits, the residual values "available" to cover stumpage fees are a function of wage rates cutters desire to achieve (Table 3.c.5.).

Table 3.c.5. Cost factors behind average post selling price at various desired wage rates (60 posts/10 hour day)

	Desired gross daily cutter earnings		
	15.00	21.00	27.00
Average selling price	85¢	85¢	85¢
Gross profit demanded by trucker	25¢	25¢	25¢
Market Transport costs	13.5	13.5	13.5
Desired payment/post (includes out-of-pocket costs of 7¢ post)	25¢	35¢	45¢
Residual for stumpage/post	21.5¢	11.5¢	1.5¢

Management of Juniper Fence Post Production - Harvesting juniper posts is almost completely non-competitive with any other use of pinyon-juniper woodlands (Table 3.a.7.). Only charcoaling or chaining trees would create any immediate interference. In the case of charcoal, interference would be minimized as long as harvesting is done by hand; any good posts would be put to one side for separate sale. Posts can also be salvaged before a given area is chained and, to some extent, following chaining.

But since charcoaling would involve permanent removal of a significant portion of a given stand, its long run effects upon post manage-

ment must be judged somewhat in the same light as those of conversion. Especially in the case of conversion, further post growth is eliminated. Thus, the question is whether or not a rotation program for pinyon posts is warranted, and under what conditions?

The work of Moessner with aerial volume tables for pinyon-juniper woodlands permits a crude prediction of inventories per acre of juniper posts. These predictions form the basis for determining the values of posts versus conversion benefits.

Table 9.c.3. (Part A) of this report sets 90-107 years as the necessary time to grow juniper posts. This is a length of time that makes the future value of successive rotations questionable. In table 3.c.6 a comparison is made between the current market value of a number of posts and the present value of an infinite stream of like numbers. Perpetual rotation at averages of 100 year intervals would only increase existing market values by 14 percent at 2 percent discount, and 1.5 percent at 4 percent discount. Of course, this assumes plantation-like, even-aged stand management when actually some smaller trees will be rising continuously through various diameter classes, making harvests at shorter intervals possible. Theoretically, at least, this should make post management more worthwhile. But as a practical matter, unless stands are very uneven-aged, the "second growth" numbers are likely to be too few per acre to warrant the effort of "continuous" harvesting. In any event, this is a problem that can be resolved, if necessary, by assuming some convenient rotation interval as was done in connection with discussion of pinyon Christmas trees. This interval could be one-half the

Table 3.c.6. Estimated value of 7-foot juniper fence posts per acre on good and poor sites in three ecological provinces

Province	Predicted		Market value @		Present value of infinite stream			
	No. of posts		current stumpage#		2%		4%	
	10-20' site	21-31' site	P. site	G. site	P. site	G. site	P. site	G. site
1. Escalante-Sevier								
15% crown cover	13	20	2.60	4.00	2.97	4.99	2.64	4.12
35% crown cover	33	69	6.60	13.80	7.55	16.59	6.71	14 22
2. La Sal								
15% crown cover	13	16*	1.95	2.40	2.13	2.89	1.98	2.47
35% crown cover	33	70	4.95	10.50	5.66	12.62	5.03	10.82
3. Coronado+								
5% crown cover	8	10*	.96-1.60	1.20-2.00	1.10-1.83	1.44-2.40	.98-1.63	1.24-2.06
25% crown cover	24	53	2.88-4.80	6.36-10.60	3.29-3.49	7.65-12.74	2.93-4.88	6.55-10.92

Province 1, 20¢; 2, 15¢; 3, 12¢-20¢; 1965 constant prices.

* Estimated.

+ Probability of error greater for this province.

Source: Table 3.a.3, Supra; Moessner (1, p.7); Replacement life from Part A, table 9.c.3.

whole growth period, say 50 years. Such an assumption would have the effect of increasing the present values of the infinite streams shown, especially where a low discount rate is used. At rates of 6-8 percent, the increases associated with an interval of 50 years would be very small.

The present values of posts on good and poor sites in the Escalante-Sevier province can be compared with the average conversion returns on similar sites, by referring to the upper portion of table 3.b.9. Comparison with conversion returns (2 percent and 4 percent discount rates) in other provinces can be made by referring to table 3.c.7. These comparisons are only worked up in terms of constant prices for posts and the "social value" of increased forage production. If the values assumed are expected to change in the near terms, suitable corrections must be made. It is clear from what is shown in table 3.c.6. that small changes in stumpage rates have a big effect on the present values of posts. These cautions aside, dense trees on good sites (20-30') may well have more than enough posts per acre offset benefits from planned chaining (completely cut over areas excepted). Any proposed chaining area, in any province, that contains good posts in quantities above 50-60 per acre is likely to have more value in its present state if it can be assumed that existing grazing levels can be maintained and that effective demand for the posts does exist. If uncut posts are located in such remote areas that only low stumpage rates can be realized, appropriate data adjustments must be made.

Table 3.c.7. Average present value of typical conversion results on good and poor sites in two ecological provinces* (various land treatments)

	Seeded sites				Unseeded sites			
	21'-31'		11'-20'		21'-31'		11'-20'	
	2%	4%	2%	4%	2%	4%	2%	4%
1. Coronado								
One-way chain	4.39	1.98	3.10	1.74	5.13	3.16	5.74	4.16
Haulapi Burns	20.61	13.83						
Dozed			10.42	7.54				
2. La Sal								
Two-way chain	13.95	8.18	14.34	7.86				
One-way chain	19.92	13.37	0.90	-1.93	5.71	3.45	5.71	3.45

* Time horizon of conversion assumed to be 40 years. No allowance for deferment. Based on average historical experience of about 40 percent of the projects listed in table 2.a.1, Supra.

References

1. Moessner, K. E. Preliminary Aerial Volume Tables for Pinyon-Juniper Stands. Intermountain Forest and Range Experiment Station, Research Paper #69, December 1962.

3.d. Firewood

The Commercial Market for Pinyon Firewood - Both pinyon and juniper are used for fuel throughout rural areas of the intermountain region, but pinyon is the most important commercially because of its suitability as fireplace wood. During the course of the present study a number of contacts were made with retail firewood dealers in the largest cities within the study area. Estimates were obtained of the volumes of pinyon sold and of average retail prices. The figures obtained from such sources

have been adjusted to allow for small retailers and direct trucker peddling. Estimates of the intermountain market for pinyon fireplace wood are presented in table 3.d.1.

Table 3.d.1. Average wholesale and retail prices and estimated demand for pinyon fireplace logs in selected markets

	Denver	Albuquerque	Salt Lake	Phoenix	Reno
Retail price/ton	35-37 ⁺	22	28-33 ⁺	45 ⁺	30
Wholesale price/ton	21	10-12	18.50-19.50	25-30	19-21
Annual demand (tons)	2,000	1,300	1,800	490*	260

* Over 50% of total is juniper.

+ Price known to include delivery.

Source: (1).

The tabulated demand of 5,750 tons per year is confined to the market centers shown. Other cities such as Las Vegas, Roswell, Pueblo, Colorado Springs, and Ogden provide additional markets for substantial amounts of pinyon fireplace wood each year. Total demand for pinyon in the region may approach 8,000 tons annually. This may be compared with total regional demand for all species of fireplace logs which probably approaches 16,000-18,000 tons per year (1, table 1). Considerably less than half of this total would be cut from public lands.

Each of the cities mentioned and especially the larger ones, receive pinyon firewood from no more than one or two well-defined geographical areas. The harvesting areas, in turn, are located where they have access advantages to the high end of the pinyon-juniper belt. Apparently there is not much overlap between post cutters and fireplace wood cutters. Access to enough pinyon, at the right distances from

the center of demand, seems to be the key to the distinction between the two cutting activities. In fact, an enormous part of the pinyon-juniper area surveyed during the present study (virtually the entire Colorado plateau) supports no significant firewood operations. But, to some degree, posts are cut everywhere. Their relatively greater profitability can absorb higher transport costs.

In addition to tree accessibility, the economic alternatives in local areas are instrumental in determining if firewood will be harvested. If existing general wage rates and employment opportunities are attractive, the physical effort required for tree harvesting has little appeal. But where chronic unemployment prevails, firewood harvesters sometimes try to lengthen the cutting season to more nearly provide year round work. The results are an excess wood supply in urban markets, downward pressures upon wholesale prices and a tendency to widen retail profit margins. Albuquerque wholesale prices (3.d.1.) reflect this kind of situation.

Private Costs and Returns from Cutting Pinyon Fireplace Wood - Wood

cutters were interviewed in person and by mail throughout the five state study area. These contacts provided additional knowledge about market demands, cutting rates, harvesting methods, equipment, truck sizes, and operating costs. Suitable allowances have been made for transportation distances in the profitability computations shown in table 3.d.2. In these examples, greater attention has been paid to handling and cutting operations than in the cases of Christmas trees and posts. Fireplace wood cutters are generally responsible for bucking

Table 3.d.2 Estimated cost breakdowns for harvesting pinyon fireplace wood - various sites and operations

	Wayne county	Duchesne county	Socorro county	Saguache county	Gila county
Direct costs					
Power saws	1.95	2.33	2.33	13.02	4.40
Hauling to marshalling point					
Distance rough roads	50	40	24	42	20
Cost	@ 9.8/4.90	@ 7.5/3.00	@ 9.8/2.35	18.96	@ .20/4.00
Bunching and bucking					
Cost of fuel	3.20	2.00	2.10	17.20	3.50
Stumpage	7.50	4.00	2.00	42.00	12.00
Hauling to market					
Distance	420	304	202	1236	180
Cost	@10.5/44.10	@10.5/31.92	@10.5/21.21	@.145/179.22	@.18/32.40
Gross Profit, excluding labor	88.35	106.75	52.51	612.60	303.70
Man hours	45	42	45	258	60
Cutting, Bucking - Bunching	37	32	40	300	50
Load - Unload		4		8	
	} 8		} 5		} 10
Drive to market		6		30	

and splitting operations in addition to wood seasoning.^{1/} Chain saw costs are also significant. Detailed breakdowns are given in table 3.d.2.

Utah and New Mexico data shown in table 3.d.3. were developed in terms of single shipments of $7\frac{1}{2}$ tons, transported to market on $2-2\frac{1}{2}$ ton trucks. Approximate seasonal harvesting rates in Socorro, Wayne, and Duchesne counties are 3, 2, and $1\frac{1}{2}$ loads per week, respectively. The Saguache county operation assumes 42 tons per week. The Gila-Payson rate is one load of 12 tons (truck and trailer) per week. In the order listed, the gross return per man per week would average \$67.53, \$58.90, \$80.70, \$94.24, \$151.85.

When drawing conclusions from these figures, it must be borne in mind that most firewood harvesting is more seasonal than is the case for posts. In the particular Colorado and Arizona operations detailed, some attempt is made to operate over a longer portion of the year. The same response can be observed in Socorro county, New Mexico, but for exactly opposite reasons. In the latter case, alternative employment is so sparse, that people flood the Albuquerque market with firewood, forcing wholesale prices to the lowest levels in the region. Utah harvesting is strictly seasonal, beginning in early October.

Management Potentials for Pinyon Fireplace Wood - Brief mention has been made of the special role transport costs play in marketing fireplace wood. Indeed, this seems to be the key variable. In comparison with

^{1/} 35-40 cords can be cut with one chain, 70-80 cords can be cut with one blade. Saws need overhaul every 200 cords.

Table 3.d.3. Costs and returns associated with the supply of pinyon fireplace wood to various markets

	Representative Retail Markets and Harvesting Areas				
	Sale Lake City	Ogden	Albuquerque	Denver	Phoenix
	Wayne county	Duchesne county	Socorro county	Saguache county	Gila county
Operation	3 men; 2-ton truck	2 men; 1 & 2-ton trucks	4 men; 2-ton truck	6-7 men; 2-ton and 65,000 semi	2 men; 2-ton and trailer
Gross receipts/load or/week	150.00	150.00	82.50	883.00	360.00
Direct costs/load or/week at hourly wage rates:					
1.00	106.65	85.25	74.99	528.40	116.30
1.25	117.90	95.75	86.24	592.90	131.30
1.50	129.15	106.25	97.49	657.40	146.30
Gross profit/cord* at average hourly wage rates:					
1.00	10.08	15.06	1.75	14.43	34.81
1.25	7.47	12.61	-0.87	11.84	32.67
1.50	4.85	10.17	-3.49	9.21	30.52

* Gross profits are exclusive of depreciation, equipment maintenance (except for power saws), and interest on capital.

the same sized truck load of posts the gross returns-less stumpage "per trip" are more than double those of firewood cutters in most instances. If it is assumed that actual cutting effort is equally demanding, the only offset is that post haulers take longer to peddle their loads and incur extra living and milage expenses. Nevertheless, though returns may be lower than for post harvesting, the markets for pinyon fireplace wood are expected to grow year by year.

As these demands are satisfied it may be possible for pinyon-juniper management agencies such as the BLM to realize somewhat higher stumpage rates per ton than is now the case. Among otherwise similar market areas, those situated nearest retail markets should command differential site rents at least to the degree of lowered transport and handling costs. But actually it is the reverse of this process which is of most interest here. Sooner or later pinyon supplies will be depleted and more distant sources will have to be tapped (in fact it may be thought desirable to begin to harvest dead and downed pinyon in "new" areas even now) This means that some estimates are needed of "maximum" harvesting distances from retail centers. Areas within these limits may then receive different management analysis than those without. (Given the location of major markets around the periphery of the study area, there is little demand for pinyon fireplace wood in most of the Colorado Plateau, much of the Great Basin and the northern parts of the San Juan Basin. For management purposes, these areas are outside existing harvesting boundaries.)

Suppose stumpage prices are manipulated downward with zero as a limit. Would this action be likely to influence the distance over which firewood cutters would be willing to transport wood? Zero

stumpage rates would induce cost savings from \$3.75 to \$7.50 per 2½ ton truckload and could push existing harvesting boundaries outward 20-40 miles without affecting the earnings potentials presented above.

Accessability and convenience of cutting areas to places of residence is also an important feature of post and firewood harvesting. It may therefore be suspected that such relatively small mileages will have little influence except in special circumstances. More importantly, as long as earnings can be maintained at least at present levels (i.e. as long as "local" wood supplies last" cutters already in business are not likely to lengthen hauling distances. In the short run any reduction in stumpage would swell possible profit margins of existing cutters. Thus it may be suspected that extension of harvesting boundaries could only be brought about by entry of new persons living in "other" areas. But "other" areas are not conveniently scattered at neat 20-40 mile intervals. The towns and appropriate access circumstances simply do not exist. New entry is more likely to come from individuals living in existing harvesting centers, so that entry will have negligible boundary effects.

The only way to alter these expectations would be for agencies to ration sale of stumpage permits in particular areas to certain cutters or groups.^{1/} This creates profit differentials but might spread cutting over wider areas.

In the final analysis management agencies can extend boundaries of harvesting areas only to a limited degree by merely altering stumpage

^{1/} In effect this is done in the Canon City District. The cutters combine into a larger group but the district maintains the kind of control over slash and clean-up activities it desires.

rates downward. In time, cutting areas will move only gradually outward from the Denver, Albuquerque, Phoenix, Las Vegas, Reno, Salt Lake City market centers. Meanwhile, any planned chaining of trees within the present harvesting boundaries should take into account losses of pinyon fireplace wood that could otherwise be utilized.^{1/}

In table 3.d.4. some estimates of possible pinyon volumes are grouped by site class in each of three ecological provinces. The

Table 3.d.4. Estimated value of per acre volumes of pinyon cordwood*

Province	Gross cords/acre ⁺		Value @	
	10-20'	21-31'	current stumpage**	
			Poor site	Good site
1. Escalante-Sevier				
% pinyon	.19	.25		
15% crown cover	.41	1.04	.72	1.77
35% crown cover	.54	1.54	.95	2.70
2. La Sal				
% pinyon	.34	.56		
15% crown cover	.73	2.40	.55	1.80
35% crown cover	.97	3.52	.73	2.64
3. Coronado				
% pinyon	.17	.36		
5% crown cover	.29	1.70	.22	1.28
25% crown cover	.44	2.47	.33	1.85

+ Estimated according to the proportions of pinyon shown.

* Assumed stumpage rates by province: 1-\$1/ton; 2-\$0.75/cord; 3-\$0.75/cord.

**No distinction between green and dead timber.

Source: Table 3.e.4. Infra for total wood values; table 3.a.3 Supra for site characteristics.

present values of these volumes are simply the stumpage value of existing stocks. No allowance is made for re-growth or rotation for the time periods

^{1/}Chaining always causes some loss and if it is combined with a windrowing operation the loss may be great.

are too long for growth from seedlings to have much effect on discounted values. It is true that successive harvests could be undertaken in uneven-aged stands. But given that growth in this type is as little as one foot in 20 years, appropriate re-cutting intervals would easily be 100 years. Again, this is a time span too great to have any measurable effect on present values.

The data shown in table 3.b.4. are computed for all provinces even though no actual permit sales will materialize over much of the area. Comparisons with average present values of chaining results on similar sites (40 year life - no deferment) can be made by referring to tables 3.b.9. and 3.c.7.

References

1. LeBaron, A. D. and W. H. Johnson. "Utah Wood and California Fireplaces," Utah Farm and Home Science, 26:1, p.7.

3.e. Pinyon-Juniper Charcoal

The Five-State Charcoal Market - Consumption of charcoal has been on the increase throughout the United States ever since the close of World War II. Most of this increase is associated with the growth of domestic demand (1, p.8). The main bulk of American charcoal originates in the Great Lakes region and in the Southern States. In these areas, substantial production takes place in facilities originally designed for wood distillation. Of the approximately 300 charcoal producers, only

about a dozen have production over 5,000-6,000 tons per year (1, p.9). The companies operating these plants dominate retail markets throughout the nation. All larger companies have "either a cheap source of raw materials and/or unique marketing outlets for some or all of their products" (1, p.9).

The majority of the charcoal consumed in Utah, Colorado, Nevada, Arizona, and New Mexico comes from east of the Mississippi. A significant amount is produced and largely consumed in California, and some small amounts are produced in Arizona and New Mexico using mesquite or pinyon for raw materials (1, p.10). During the course of the present study it was discovered that some Mexican charcoal is bulked shipped to Arizona, bagged and sold at quite competitive prices. This suggests that small charcoal producers can establish themselves and successfully compete for local markets in the west, just as elsewhere in the nation (1, p.9).

An obvious source of raw materials for production of charcoal in the Intermountain area is pinyon-juniper. Recent studies of the technological aspects of charcoaling these varieties of wood suggest that an acceptable product can be made, but costs are not particularly favorable (2, p.1). Pinyon-juniper production and delivery costs are compared with wholesale prices of popular brands later in this sub-section.

In table 3.e.1. the current estimated regional demand for charcoal is presented. This is considerably higher than estimates made in 1959, and there is no reason to suspect that the growth indicated should cease.^{1/} Per capita consumption in the western states is consistently above the national average.

^{1/} Sales gains of 30 percent to 100 percent per year in the early 1960's have been common for many distributors in the study area.

Table 3.e.1. Estimated five-state demand for charcoal - tons (1959-1965)

Year	Total 5-states	Utah	Colorado	New Mexico	Arizona	Nevada
1959	5,800	1,100		4,000	to 5,000	
1964	13,675	2,000	4,600	1,615	3,560	900

Source: (1, p.11); letters and interviews with large charcoal distributors in five states.

The degree to which pinyon-juniper charcoal could command a share of this market remains a matter for speculation. But if costs are at all competitive, the proper marketing and promotional activities should result in a worthwhile level of penetration, for test batches of pinyon-juniper charcoal seem to have a satisfactory appearance in their lump state.

Per Ton Cost of Making Lump Charcoal - The technique and cost of producing lump charcoal in portable sheetmetal kilns that can be shifted to various pinyon-juniper sites has recently been investigated (2). One of the most important conclusions of this study is that there are several distinct advantages associated with lump charcoal. The most important of these are ease of lighting and relatively short burning time (45 minutes). The production costs shown below have been taken from this report.

None of the costs listed in tables 3.e.2. and 3.e.3. make allowance for taxes, insurance, or other fixed expenses (except for the kilns and chain saws). The direct costs of obtaining a ton of charcoal from either species under the density conditions assumed are about \$43.09 and \$50.58 for pinyon and juniper respectively.

Table 3.e.2. Wood inputs and costs per ton of charcoal (labor cost, 1.25/hr.)

	Pinyon	Mixed	Juniper
Cords of wood	2.75		3.25
Man hours to cut, stack, and load	11		13
Acres harvested ⁺	2.0	1.33	3.5
Labor cost	\$13.75		\$16.80
Cost @ 8¢/mile (4 miles round trip)	.64		.75
Chain saw	1.93		2.28
Stumpage	1.37		1.63
Harvest cost at Kiln	\$17.69		\$21.46

⁺ Average of six $\frac{1}{2}$ acre plots in Hamblin Valley, So. Western Utah. Only trees greater than 6" in diameter are taken.

Table 3.e.3. Pinyon-juniper charcoal production costs

	Pinyon	Juniper
Sorting, bucking at Kiln	\$ 1.00	\$ 1.10
Loading and unloading Kiln	4.75	5.25
Tending kiln	1.15	1.25
Sacking in 10# bags	11.00	12.75
Bags	5.50	6.37
Kiln depreciation	2.00	2.40
Kiln cost per ton	\$25.40	\$29.12

Source: (2, p.4).

In addition to these sums transportation cost to market centers must be calculated at 1.0 to 1.5 cents per mile depending on how small a truck is used. If there is no return load, these allowances for mileage costs must be doubled. To ship lump charcoal from Hamblin Valley, Utah to Salt Lake City, for example, would add 270 miles @ 1.2 cents on average, or \$3.24 per ton. This would bring the total for pinyon to about \$46.50 per ton. If fixed transport costs are considered, this latter value would have to be increased by an additional \$5.00 per ton. Finally, it is likely that some warehousing expenses would be incurred. This might add another \$3.00 to \$5.00 per ton (2, p.4).

The grand total delivered to wholesalers, say, in Salt Lake City, would be about \$50.00 per ton for pinyon and \$55.00 for juniper. The price for mixed wood would be less than either of the above figures due to lower labor costs associated with harvesting fewer acres.

Wholesale costs of hardwood brickettes (10# bags) delivered in Salt Lake City are \$100.00-\$120.00 per ton. Lignite costs are somewhat lower, \$83.00-\$100.00 per ton. Most of the variation in wholesale cost is due to shipment size. The lowest costs require a minimum purchase of an 80,000 pound car. Wholesale prices in Denver, Albuquerque, and Phoenix are somewhat lower because of lower freight costs.

Thus, out of an indicated cost differential of about \$30.00 per ton compared with lignite charcoal, a pinyon-juniper producer would have to recover any depreciation not mentioned earlier, driver's wages, interest on capital, and manager's wages or returns. Other expenses would be connected with advertising and promotion. Assuming that a market for lump pinyon-juniper charcoal could be created, the net

private returns would be modest rather than spectacular. Even so, they are likely to be greater per ton than for any other pinyon-juniper wood product (except Christmas trees).

Management Options for Charcoal Producing Areas - The potential returns to the Bureau of Land Management or any other agency from sales of pinyon-juniper cord wood can be analyzed in the same framework as other products. In table 3.e.4. potential cord wood volumes have been associated with crown cover and site class.^{1/} The values shown are based on an assumed stumpage rate of 50 cents per cord. This may be too low because pinyon firewood cutters pay considerably more stumpage except on Forest Service sites in New Mexico. However, any other convenient price can be assumed as desired. For example, a \$1.00 rate would simply double the returns figures, etc. Infinite discounting over replacement intervals shown in table 9.c.3. (Part A) have practically no effect on the values of the initial stands.

Comparisons with average returns for various combinations of chaining and seeding treatments may be made by referring to tables 3 b.9. and 3.c.7. of this section. Stumpage rates of about \$4.00 per cord would be required to offset gains from conversion in many instances. If actual inventories are available, comparisons may be tightened considerably. In addition, a further tightening is possible, in this instance as well as in all earlier product examples, if the specific conversion benefits are computed for the site in question using techniques shown in chapter 2 of this part of the report.

^{1/} In an absence of a woodland inventory these are the only estimates possible. The values shown for cordage are too high for charcoaling purposes since it is recommended that trees under 6" diameter be ignored (2). For comparison with the cordage shown the actual number of cords suitable for charcoaling on six $\frac{1}{2}$ acre South-western Utah plots ranged from $1\frac{1}{2}$ to 3 cords per plot with an average of $2\frac{1}{2}$ cords (2).

Table 3.e.4. Estimated value of per acre volumes of pinyon-juniper type if charcoaled

Province	Gross cords/acre		Value @		Present value of infinite stream			
	10-20'	21-31'	current prices ⁺		2%		4%	
	site	site	P site	G site	P site	G site	P site	G site
1. Escalante-Sevier								
15% crown cover	2.14	4.14	1.07	2.07	1.10	2.16	1.07	2.07
35% crown cover	2.85	6.14	1.42	3.07	1.46	3.21	1.42	3.07
2. La Sal								
15% crown cover	2.14	4.28	1.07	2.14	1.10	2.24	1.07	2.14
35% crown cover	2.85	6.28	1.42	3.14	1.46	3.28	1.42	3.14
3. Coronado								
5% crown cover	1.71	4.71	.86	2.36	.88	2.46	.86	2.36
25% crown cover	2.57	6.58	1.29	3.43	1.33	3.58	1.29	3.43

⁺ Assumed selling price of mixed pinyon-juniper per cord = 50¢.

Source: Table 3.a.3 Supra; Moessner (3, p.6).

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4. NOTES ON WATERSHED AND WILDLIFE MANAGEMENT⁺ VS. PINYON-JUNIPER CONTROL⁺

The ecological team surveys reported in Part A and the references cited therein have abundantly documented the fact that increases in forage production follow pinyon-juniper removal in New Mexico and Arizona. Given adequate management, most appropriate sites in these states have enough understory of native grasses to respond to a reduction in moisture competition and poisoning from tree litter. In Utah, Colorado and Nevada, where seeding adapted species is often part of the control process, greatly increased forage yields are possible if good establishment is achieved. The effects of tree removal on big game food and cover, soil erosion and water yields are not as well known. Studies are underway to learn more about these relationships, but published literature suggests that most research to date has been accomplished in Arizona and New Mexico. Such data may or may not be applicable to public lands management at higher latitudes.

4.a. Watershed Management

The area covered by the present study is large and this leads to some diversity of watershed goals between regions. For example, the goal of increasing water yields seems widely accepted in Arizona and

⁺The ecological phase of the present project was not designed to consider watershed or wildlife relationships. Hence, no project data are available for any level of economic analysis.

New Mexico. In that region higher yields are desired as long as particularly adverse affects upon plant life can be avoided and erosion can be minimized. In more northerly parts of the Colorado Plateau there are huge regions where the watersheds receive so little rainfall on a per acre basis that purely "local" beneficial use in the usual sense is not a possibility. Ephemeral run-off from what is largely pinyon-juniper area finally winds up in the Colorado River and "beneficial use" occurs in very distant regions. The most beneficial local use of low precipitation amounts in the entire central portion of the present study area might be to reduce water yields if such action induces positive increases in local forage production.

These somewhat different attitudes in fact seem to explain some of the research emphasis one encounters in research reports of 15 to 20 years ago. In 1949, the Rocky Mountain Experiment Station reported that in western and southwestern Colorado study sites, infiltration was higher and erosion lower under modest grazing (11, p.66), infiltration rates were higher for sagebrush parks than for pinyon-juniper lands (11, p.67), and infiltration higher and erosion lower than in adjacent ungrazed areas (11, p.67). And the emphasis was still upon infiltration rates in a northern New Mexico study reported by the Rocky Mountain Forest and Range Experiment Station in 1954 (11, p.43-44). One section of Plummer's 1958 study of restoration of Utah pinyon-juniper range also emphasized erosion and lack of infiltration (characteristic of situations where ground cover is so sparse beneath the trees) (8, p.209).

Other findings of earlier research are that crown canopy can significantly reduce the amount of precipitation reaching the ground (12, p.27-28), and that vegetation and litter have a positive effect

upon water absorption (2, p.25). It must be recognized that most water yield from this type comes as surface run-off (2, p.24).

However, by 1960 the key question for New Mexico and Arizona researchers was whether or not water yields could be increased. Dortignac's AAAS paper of that year had this orientation and he concluded that prospects were small (2). He feared that any vegetation manipulation would be likely to increase erosion and sediment (2, p.26). Subsequent research at Beaver Creek in Arizona has only partially confirmed his views.

Experiments to determine effects of cabling Utah juniper on the Beaver Creek watershed date back to 1957. Eight years of data have been analyzed and reported. And as predicted, there has been no significant change in water yield, summer or winter (1, p.20). Concerning sedimentation, results obtained thus far do not substantiate Dortignac's position. "There has been no measurable change in either the sedimentation-concentration discharge relationship or in bedload and suspended sediment yields" (1, p.20). These are preliminary results, but as native grasses continue recovery, there would seem to be little reason to expect future water yields to increase.

There have been unpublished reports that U. S. Geological Survey research on Indian reservation lands in Arizona (esp. Ft. Apache) suggest the same preliminary conclusions. A statistically significant difference in water yield from areas with and without pinyon-juniper has not been detected. "The data indicates that it would take 50 years to accumulate enough information to handle the extremes in variance" (5).

For the present, it must be concluded that changes in watershed values due to increases or decreases in water yields may not be important enough to consider in pinyon-juniper management. And as long as extreme slopes are avoided, it is completely possible that slash and litter produced by chaining actually improve erosion control (Part A, p.201-202; 3, p.6).

4.b. Wildlife Management

Any assessment of the effects of pinyon-juniper control on game herds must be conditioned by data availability--literature is sparse, fragmented and inconclusive. The Bureau of Land Management is itself conducting a study of deer use on a chained area south of Wells Nevada (13). Publication of specific results are not available as this is written. Research by the Arizona Game and Fish Department goes back at least to 1960 (6; 7). The Rocky Mountain Forest and Range Experiment Station began wildlife habitat studies before 1960, but only "intensified" this work beginning in 1961 (11, p.2). Whether or not pinyon-juniper control has been "beneficial" to deer herds (as alledged by BLM spokesmen [4]) depends upon the goals of the analysis employed. For example, if the analysis requires determination of the effect of control on total deer numbers, nothing can be said one way or another. The typical method of estimating increased species utilization, and demarcating preferred living areas (by pellet counts) does not allow conclusions about cause and effect on total game populations. And surely, in the first instance, it is a matter of totals that is important in valuing game effects. Are there more deer? Are there more

deer to be taken as a result of chaining? These are the relevant questions. (Of course if control affects food supplies so that deer become thinner or fatter, some allowance for alterations in value could be made.)

It seems clear that if the only issue is whether the deer are "driven away" by tree control measures, or attracted by them, the intrinsic value of a given number of animals has not changed. If the animals do congregate in controlled areas, for whatever reasons, it might be said that hunters are benefited if successes are more readily comeby. But how is this success to be valued? While it is a common thing for state fish and game departments to place values on numbers of deer killed, to attempt to value increments in the ease or difficulty of hunting effort would be going a bit far. Thus, the only [valuation] question for which current habitat research can provide a valid answer is whether big game feed better as a result of pinyon-juniper control on critical winter ranges.

In 1961 it was reported that deer were well distributed in both pineland and junipers during spring and summer at Beaver Creek; concentration in junipers began in fall and winter. Elk pellets were found in junipers in 1959 but not in 1960-1961. Elk used the chained and reseeded juniper areas more than deer. Elk use was up twenty times compared with the surrounding areas. "A surprisingly large portion of total [rumen] contents of fall and winter killed deer was Utah and alligator juniper and shrub live oak" (11, p.91-92).

During the period 1958-1962 there was a progressive decrease in deer use on the Beaver Creek area experimental watershed. But Arizona game and fish personnel did not blame the watershed study (6, p.5).

Differences in pellet counts between cleared juniper areas and adjacent uncleared areas showed "no convincing patterns" (6, p.5). At higher elevations, in mixed conifers, slope aspects, by compass quarter, were not detectable factors in game preferences (6, p.11).

In the Grapevine (Arizona) areas, density of deer pellet groups was greater on two small cabled plots than on surrounding areas within six chains around the plot edges (7, p.2). Browse density five years after cabling was sparse. The deer appeared to have been maintained largely on forage other than browse species (7, p.3). "On sampled areas of the north Kiabab during the fifth to seventh year after juniper-pinyon control, there appeared to be no preference of deer for the tree eradication areas as compared with areas of standing trees" (7, p.3).

Reporting elk and deer habitat use of pinyon-juniper woodland at Fort Bayard in southwest New Mexico, Reynolds found a simple correlation coefficient of .71 between elk and deer pellets (10, p.440). Northeastern exposures had 40 to 100 percent greater counts than other quadrants (10, p.440). Shrubs appeared to influence pellet locations to a greater degree than did trees (10, p.440). Pellet groups were numerous on slopes over 40 percent (10, p.441). Reynolds suggests that for Fort Bayard conditions: clear pinyon-juniper only on slopes less than 15 percent; leave existing cover on northeastern slopes; remove trees which overtop shrubs where they exceed about 150 trees per acre; cut back shrubs that are so tall as to be inaccessible to elk and deer (10, p.443).

Importance of "edge effect" for deer and elk was reported in 1965 for both the Kiabab and Apache national forests. But the data were

collected in the mixed-conifer zone (11, p.17) With respect to reported pinyon-juniper data, nothing in the literature review suggests any definite conclusions about an edge effect.

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APPENDIX GIVING ECOLOGICAL TEAM PLOT LOCATIONS

The only plots identified by district and agency numbers are those connected with revegetation or pinyon-juniper control of some type. The letter designation given for the tree plots only clearly indicate the general district or agency having management control of the area. The plot numbers listed can be used in connection with tables presented in Part A of the present report.

Species	Plot No.	Letter Designation	Location	Agency	District Name	Project Number	Local Name
PE,JO	1	Ut-Pr-1	SE $\frac{1}{4}$,Sec.36,T15S,R 8E				
PE,JO	2	Ut-Pr-2	NW $\frac{1}{4}$,Sec.16,T16S,R 9E				
PE,JO	3	Ut-Pr-3	NW $\frac{1}{4}$,Sec. 7,T14S,R13E	BLM	Price	U7-R-198	No. Clark's Valley
PE,JO	4	Ut-Pr-4	SE $\frac{1}{4}$,Sec.27,T16S,R13E				
PE,JO	5	Ut-Pr-5	NW $\frac{1}{4}$,Sec.14,T12S,R14E				
PE,JM	6	Ut-Pr-6	NW $\frac{1}{4}$,Sec.13,T12S,R14E				
PE,JO	7	Ut-Pr-7	SW $\frac{1}{4}$,Sec.28,T14S,R 8W	BLM	Price	U7-R-137	Pinnacle
PE,JO	8	NM-Fr-1	NW $\frac{1}{4}$,Sec. 8,T32N,R 9W	BLM	Farmington	NM7-R-364	Blancett
PE,JO	9	NM-Fr-2a	SE $\frac{1}{4}$,Sec.13,T32N,R10W				
PE,JO	10	NM-Fr-3	SW $\frac{1}{4}$,Sec.33,T30N,R10W	BLM	Farmington	NM-R-152	Robb Brothers
PE,JO	11	NM-Fr-4	SW $\frac{1}{4}$,Sec.22,T31N,R10W				
PE,JM	12	NM-Fr-5	NE $\frac{1}{4}$,Sec. 2,T32N,R10W				
PE,JO	13	NM-Fr-6	SW $\frac{1}{4}$,Sec.23,T32N,R10W	BLM	Farmington	NM7-356	Mass Cedar
PE,JO	14	NM-Fr-7	T30N,R12W				
PE,JO	15	NM-So-1	SE $\frac{1}{4}$,Sec. 1,T 3S,R 6W				
PE,JO	16	NM-So-2	NE $\frac{1}{4}$,Sec.31,T 3S,R 5W				
PE,JO	17	NM-So-3	NW $\frac{1}{4}$,Sec.32,T 2S,R 5W				
PE,JO	18	NM-So-4	NE $\frac{1}{4}$,Sec.33,T 2S,R 5W				
PE,JO	19	NM-So-5	SE $\frac{1}{4}$,Sec.34,T 2S,R 3E				
PE,JO	20	NM-So-6	NW $\frac{1}{4}$,Sec.29,T 2S,R 3E				
PE,JS,JD,JO	21	NM-So-7	NW $\frac{1}{4}$,Sec.27,T 1N,R11W				
PE,JM,JD	22	Ar-Sh-1	NE $\frac{1}{4}$,Sec.23,T10N,R22E				
PE,JM	23	Ar-Sh-2	SE $\frac{1}{4}$,Sec. 4,T11N,R23E	FS	Lakeside		Ortega Lake
JM	24	Ar-Sh-3	SE $\frac{1}{4}$,Sec. 4,T11N,R25E				
PE,JM	25	NM-A1-1	NW $\frac{1}{4}$,Sec.19,T17N,R 2W				
PE,JM	26	NM-A1-2	NE $\frac{1}{4}$,Sec.13,T17N,R 3W				
PE,JM	27	NM-A1-3	SW $\frac{1}{4}$,Sec.14,T17N,R 3W				
PE,JO,JS	28	NM-A1-4	NW $\frac{1}{4}$,Sec.24,T24N,R 2W				
PE,JO,JS	29	NM-A1-5	NW $\frac{1}{4}$,Sec.24,T24N,R 2W				
PE,JM	30	NM-A1-6	NE $\frac{1}{4}$,Sec.10,T21N,R 3W				
PE,JM	31	NM-A1-7	NE $\frac{1}{4}$,Sec. 3,T21N,R 2W	BLM	Albuquerque	NM-1-1	Stroyer
PE,JM	32	NM-A1-8	NE $\frac{1}{4}$,Sec. 8,T21N,R 2W				
PE,JM	33	NM-A1-9	NE $\frac{1}{4}$,Sec. 4,T19N,R 1W				

PE, JM	34	NM-A1-10	NW $\frac{1}{4}$, Sec. 9, T20N, R 1W				
PE, JO	35	Ut-Mo-1	NE $\frac{1}{4}$, Sec. 1, T29S, R25E				
PE, JO	36	Ut-Mo-2	NW $\frac{1}{4}$, Sec. 7, T29S, R26E				
PE, JO	37	Ut-Mo-3	NE $\frac{1}{4}$, Sec. 16, T29S, R26E				
PE, JO	38	Ut-Mo-4	NW $\frac{1}{4}$, Sec. 11, T37S, R18E	BLM	Monticello	U6-R 4	Cyclone Flats
PE, JO	39	Ut-Mo-5	NW $\frac{1}{4}$, Sec. 19, T37S, R19E				
PE, JO	40	Ut-Mo-6	NW $\frac{1}{4}$, Sec. 32, T33S, R25E				
PE, JO	41	Ut-Mo-7	NE $\frac{1}{4}$, Sec. 35, T33S, R26E				
PE, JO	42	Co-Du-1	SE $\frac{1}{4}$, Sec. 19, T36N, R14W				
PE, JO	43	Co-Du-2	Sec. 22, T36N, R15W	BLM	Durango	C4-R-178	Grade
PE, JO	44	Co-Du-3	SE $\frac{1}{4}$, Sec. 21, T36N, R15E				
PE, JO	45	Co-Du-4	SE $\frac{1}{4}$, Sec. 6, T31N, R14W				
PE, JO	46	Co-Du-5	SW $\frac{1}{4}$, Sec. 32, T35N, R14W				
PE, JO	47	Co-Du-6	SE $\frac{1}{4}$, Sec. 30, T35N, R14W				
PE, JO	48	Co-Du-7	SW $\frac{1}{4}$, Sec. 5, T32N, R 8W	BIA	Con-Ute Agency		Mesa Mt.
PE, JO	49	Co-Du-8	SW $\frac{1}{4}$, Sec. 26, T37N, R20W	BLM	Durango	C4-333	Dumpy
PE, JO	50	Co-Du-9	SW $\frac{1}{4}$, Sec. 26, T37N, R20W				
PE, JO	51	Co-Du-10	SE $\frac{1}{4}$, Sec. 27, T38N, R18W				
PE, JM, JO	52	Ar-Flag-1	NE $\frac{1}{4}$, Sec. 16, T23N, R 8E	FS	Elden Dist.		
PE, JM, JO	53	Ar-Flag-2	SW $\frac{1}{4}$, Sec. 3, T24N, R 8E				
PE, JM	54	Ar-Flag-3	NW $\frac{1}{4}$, Sec. 9, T24N, R 8E				
PE, JM	55	Ar-Flag-4	Sec. 28, T12N, R20E				
PM, JO	56	Ar-Flag-5	Sec. 1, T11N, R19E				
PM, JO, JM	57	Ar-Flag-6	NE $\frac{1}{4}$, Sec. 29, T14N, R 6E				
JO	58	Ar-Flag-7	SW $\frac{1}{4}$, Sec. 26, T14N, R 6E				
PM, JO	59	Ar-Flag-8	NE $\frac{1}{4}$, Sec. 31, T17N, R 6E	BLM	Phoenix	284	Bogle
JO, JD, PE	60	Ar-Wil-1	Sec. 11, T22N, R 2E				
PE, JD, JO	61	Ar-Wil-2	Sec. 31, T20N, R 2E				
PE, JO	62	Ar-Wil-3	Sec. 13, T19N, R 1E				
PM, JO	63	Ar-Wil-4	Sec. 27, T18N, R 5W				
PM, JD	64	Ar-Wil-5	Sec. 7, T12N, R 5W				
PM, JO	65	Ar-Wil-6	Sec. 4, T18N, R 5W				
JO, PE	66	Ar-Hu-1	NE $\frac{1}{4}$, Sec. 32, T26N, R 9W				
PE, JO	67	Ar-Hu-2	SW $\frac{1}{4}$, Sec. 36, T28N, R 8W				
PE, JO	68	Ar-King-1	NE $\frac{1}{4}$, Sec. 2, T24N, R12W				
JO, PM	69	Ar-King-2	NW $\frac{1}{4}$, Sec. 11, T25N, R12W				
PM, PE, JO	70	Ar-King-3	NW $\frac{1}{4}$, Sec. 5, T25N, R13W				

JO, PE	71	Ar-King-4	SE $\frac{1}{4}$, Sec. 1, T23N, R12W
JO	72	Ar-King-5	NE $\frac{1}{4}$, Sec. 26, T23N, R12W
JO	73	Ar-King-6	SW $\frac{1}{4}$, Sec. 11, T23N, R12W
JO	74	Ar-King-7	Sec. 11, T22N, R17W
JO	75	Ar-King-8	Sec. 11, T22N, R17W
PM, JO	76	Ar-King-9	NW $\frac{1}{4}$, Sec. 4, T20N, R15W
PM, JO	77	Ne-Lv-1	SW $\frac{1}{4}$, Sec. 11, T 2S, R69E
PM, JO	78	Ne-Lv-2	NE $\frac{1}{4}$, Sec. 36, T 2S, R69E
PM, JO	79	Ne-Lv-3	NW $\frac{1}{4}$, Sec. 23, T 3S, R70E
PM, JO	80	Ne-Lv-4	Sec. 29, T 5S, R68E
PM, JO	81	Ne-Lv-5	SE $\frac{1}{4}$, Sec. 22, T 5S, R68E
PM, JO	82	Ne-Lv-6	NW $\frac{1}{4}$, Sec. 25, T 5S, R67E
JO	83	Ne-Lv-7	SE $\frac{1}{4}$, Sec. 25, T 1N, R67E
PM, JO	84	Ne-Lv-8	SW $\frac{1}{4}$, Sec. 2, T 1N, R66E
JO	85	Ne-Lv-9	SW $\frac{1}{4}$, Sec. 28, T 4N, R66E
PM, JO	86	Ne-Ey-1	SE $\frac{1}{4}$, Sec. 12, T11N, R64E
PM	87	Ne-Ey-2	SW $\frac{1}{4}$, Sec. 20, T12N, R65E
PM, JO	88	Ne-Ey-3	NW $\frac{1}{4}$, Sec. 24, T13N, R64E
JO	89	Ne-Ey-4	NE $\frac{1}{4}$, Sec. 12, T15N, R55E
PM, JO	90	Ne-Ey-5	SW $\frac{1}{4}$, Sec. 19, T15N, R55E
PM, JO	91	Ne-Ey-6	SE $\frac{1}{4}$, Sec. 6, T22N, R65E
PM, JO	92	Ne-Ey-7	NW $\frac{1}{4}$, Sec. 1, T22N, R65E
PM, JO	93	Ne-Ey-8	NE $\frac{1}{4}$, Sec. 33, T23N, R65E
PM, JO	94	Ne-Ek-1	SW $\frac{1}{4}$, Sec. 21, T31N, R62E
PM, JO	95	Ne-Ek-2	SE $\frac{1}{4}$, Sec. 20, T31N, R63E
PM, JO	96	Ne-Ek-3	NW $\frac{1}{4}$, Sec. 5, T31N, R64E
PM, JO	97	Ne-Ek-4	SE $\frac{1}{4}$, Sec. 2, T37N, R63E
PM, JO	98	Ne-Ek-5	SE $\frac{1}{4}$, Sec. 36, T38N, R63E
PM, JO	99	Ne-Ek-6	SW $\frac{1}{4}$, Sec. 33, T37N, R66E
PM, JO	100	Ne-Ek-7	SE $\frac{1}{4}$, Sec. 2, T31N, R68E
PM, JO	101	Ne-Ek-8	SW $\frac{1}{4}$, Sec. 26, T32N, R68E
PM, JO	102	Ne-Ek-9	SE $\frac{1}{4}$, Sec. 6, T29N, R69E
PM, JO	103	Ne-Ey-9	SE $\frac{1}{4}$, Sec. 33, T16N, R62E
PM, JO	104	Ne-Ey-10	SE $\frac{1}{4}$, Sec. 2, T17N, R61E
PM, JO	105	Ne-CC-1	NE $\frac{1}{4}$, Sec. 4, T14N, R21E
PM, JO	106	Ne-CC-2	NW $\frac{1}{4}$, Sec. 9, T14N, R21E

BLM

Phoenix

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Lawrence-Stegall-Cook

PM,JO	107	Ne-CC-3	SE $\frac{1}{4}$,Sec.27,T14N,R22E				
PM,JO	108	Ne-CC-4	NE $\frac{1}{4}$,Sec.19,T14N,R22E				
PM,JO	109	Ne-CC-5	SW $\frac{1}{4}$,Sec.30,T14N,R22E				
PM,JO	110	Ne-CC-6	NE $\frac{1}{4}$,Sec. 5,T13N,R21E				
PM,JO	111	Ne-CC-7	NE $\frac{1}{4}$,Sec. 3,T13N,R21E				
PM,JO	112	Ne-Winn-1	SE $\frac{1}{4}$,Sec.32,T26N,R37E				
PM,JO	113	Ne-Winn-2	SW $\frac{1}{4}$,Sec. 5,T26N,R37E				
PM,JO	114	Ne-Winn-3	SE $\frac{1}{4}$,Sec.11,T27N,R37E				
JO	115	Ne-Winn-4	NE $\frac{1}{4}$,Sec.25,T28N,R39E				
JO	116	Ne-Winn-5	SE $\frac{1}{4}$,Sec.14,T28N,R39E				
JO	117	Ne-Winn-6	SE $\frac{1}{4}$,Sec.23,T28N,R39E				
PM,JO	118	Ne-BM-1	Sec. 9,T22N,R42E				
PM,JO	119	Ne-BM-2	Sec. 7,T23N,R50E				
PM,JO	120	Ne-BM-3	Sec. 6,T23N,R50E				
PM,JO	121	Ar-Stg-1	SE $\frac{1}{4}$,Sec. 3,T39N,R12W				
PM,JO	122	Ar-Stg-2	Sec.14,T39N,R12W				
PM,JO	123	Ar-Stg-3	NE $\frac{1}{4}$,Sec.31,T39N,R12W				
PE,JO	124	Ar-Stg-4	NW $\frac{1}{4}$,Sec.22,T36N,R 9W				
PE,JO	125	Ar-Stg-5	NE $\frac{1}{4}$,Sec. 1,T35N,R 8W				
PE,JO	126	Ar-Stg-6	NW $\frac{1}{4}$,Sec. 5,T39N,R 1W				
PE,JO	127	Ar-Stg-7	SE $\frac{1}{4}$,Sec.35,T39N,R 1W				
PE,JO	128	Ar-Stg-8	SW $\frac{1}{4}$,Sec.36,T39N,R 1W				
JO	129	Ut-Ka-1	NW $\frac{1}{4}$,Sec. 1,T41N,R 1E				
PE,JO	130	Ut-Ka-2	SE $\frac{1}{4}$,Sec.13,T43S,R 4W	BLM	Kanab	U11-R-42	Vermillion 2
PE,JO	131	Ut-Ka-3	NW $\frac{1}{4}$,Sec.11,T41S,R 5W				
PE,JO	132	Ut-Ka-4	NW $\frac{1}{4}$,Sec. 6,T41S,R 5W				
PE,JO	133	Ar-Stg-9	SE $\frac{1}{4}$,Sec.20,T39N,R 1E	FS	Jacob Lake	---	Ryan (?)
PE,JO	134	Ar-Stg-10	NE $\frac{1}{4}$,Sec.13,T38N,R 1W	FS	Jacob Lake	---	Ryan (?)
PE,JO	135	Ut-CC-1	SW $\frac{1}{4}$,Sec.23,T31S,R16W				
PM,JO	136	Ut-CC-2	NW $\frac{1}{4}$,Sec. 7,T30S,R17W	BLM	Cedar City	U4-R-75	Pine Valley
PM,JO	137	Ut-CC-3	SW $\frac{1}{4}$,Sec.10,T30S,R17W				
PM,JO	138	Ut-CC-4	Sec.12,T34S,R24W				
PM,JO	139	Ut-CC-5	Sec.36,T33S,R20W				
PM,JO	140	Ut-CC-6	NE $\frac{1}{4}$,Sec.35,T33S,R12W	BLM	Cedar City	466	Perrywell
JO	141	Ut-CC-7	NE $\frac{1}{4}$,Sec.26,T34S,R12W				
PE,JO	142	Ut-CC-8	SE $\frac{1}{4}$,Sec. 2,T35S,R12W				

JO	143	Co-Cr-1	NE $\frac{1}{4}$, Sec. 5, T 7N, R97W	BLM	Craig	C1-R-96	Godiva #1
JO	144	Co-Cr-2	SW $\frac{1}{4}$, Sec. 15, T10N, R97W				
PE, JO	145	Co-Cr-3	SE $\frac{1}{4}$, Sec. 35, T 1N, R99W	BLM	Craig	C1-R-82	Upper Barcus
PE, JO	146	Co-Cr-4	SW $\frac{1}{4}$, Sec. 19, T 1N, R98W				
PE, JO	147	Co-Cr-5	SE $\frac{1}{4}$, Sec. 16, T 1N, R97W				
PE, JO	148	Co-Cr-6	SE $\frac{1}{4}$, Sec. 20, T 1N, R97W				
PE, JO	149	Co-Cr-7	NW $\frac{1}{4}$, Sec. 5, T 1S, R97W				
PE, JO	150	Co-Gj-1	NW $\frac{1}{4}$, Sec. 15, T13S, R102W	BLM	Grand Junction	C7-R-7	Timber Ridge 1
PE, JO	151	Co-Gj-2	NE $\frac{1}{4}$, Sec. 10, T13S, R102W	BLM	Grand Junction	C7-R-7	Timber Ridge 2
PE, JO	152	Co-Gj-3	SE $\frac{1}{4}$, Sec. 9, T 9S, R98W				
PE, JO	153	Co-Gj-4	SW $\frac{1}{4}$, Sec. 14, T 9S, R99W				
PE, JO	154	Co-Gj-5	SE $\frac{1}{4}$, Sec. 20, T12S, R97W	BLM	Grand Junction	---	Kanah Creek
PE, JO	155	Co-Gj-6	SW $\frac{1}{4}$, Sec. 21, T12S, R97W	BLM	Grand Junction	---	Kanah Creek
PE, JO	156	Co-Gj-7	SE $\frac{1}{4}$, Sec. 18, T12S, R98W				
PE, JO	157	Co-Mo-1	NW $\frac{1}{4}$, Sec. 31, T49N, R11W	BLM	Montrose	C3-R-78	Roubideau
PE, JO	158	Co-Mo-2	Sec. 16, T49N, R11W				
PE, JO	159	Co-Mo-3	SE $\frac{1}{4}$, Sec. 10, T49N, R11W				
PE, JO	160	Co-Mo-4	NW $\frac{1}{4}$, Sec. 36, T48N, R11W	BLM	Montrose	C3-R-278	Donnelly 1
PE, JO	161	Co-Mo-5	SW $\frac{1}{4}$, Sec. 19, T48N, R10W	BLM	Montrose	C3-R-278	Donnelly 1
PE, JO	162	Co-Mo-6	NW $\frac{1}{4}$, Sec. 16, T48N, R10W				
PE, JO	163	Co-Mo-7	SW $\frac{1}{4}$, Sec. 2, T49N, R11W				
PE, JO	164	Co-Mo-8	NW $\frac{1}{4}$, Sec. 10, T49N, R11W				
PE, JO	165	Ut-Ri-1	SE $\frac{1}{4}$, Sec. 29, T30S, R11E				
PE, JO	166	Ut-Ri-2	NE $\frac{1}{4}$, Sec. 13, T31S, R10E				
PE, JO	167	Ut-Ri-3	NW $\frac{1}{4}$, Sec. 21, T32S, R10E	BLM	Richfield	435	Airplane Springs
PE, JO	168	Ut-Ri-4	SE $\frac{1}{4}$, Sec. 16, T32S, R10E				
PE, JO	169	Ut-Ri-5	NE $\frac{1}{4}$, Sec. 8, T29S, R 6E				
PE, JO	170	Ut-Ri-6	SW $\frac{1}{4}$, Sec. 5, T29S, R 6E				
PE, JO	171	Ut-Fi-1	NW $\frac{1}{4}$, Sec. 24, T28S, R 7W	BLM	Fillmore	413	Porcupine
PE, JO	172	Ut-Fi-2	Sec. 18, T28S, R 6W				
JO	173	Ut-Fi-3	NE $\frac{1}{4}$, Sec. 34, T27S, R 8W	BLM	Fillmore	468	Shag Hollow
PE, JO	174	Ut-Fi-4	NW $\frac{1}{4}$, Sec. 11, T28S, R 8W				
PE, JO	175	Ut-Fi-5	NE $\frac{1}{4}$, Sec. 7, T29S, R 8W				
JO	176	Ut-Fi-6	SW $\frac{1}{4}$, Sec. 16, T28S, R 8W	BLM	Fillmore	399	Porcupine
PM, JO	177	Ut-Mu-1	SE $\frac{1}{4}$, Sec. 13, T 9S, R 4W				
PM, JO	178	Ut-Mu-2	SW $\frac{1}{4}$, Sec. 15, T 9S, R 4W				

JO	179	Ut-Fi-7	NE $\frac{1}{4}$, Sec. 19, T12S, R 4W			
JO	180	Ut-Fi-8	Sec. 35, T12S, R 4W			
JO	181	Ut-Fi-9	NW $\frac{1}{4}$, Sec. 1, T11S, R 3W	BLM	Fillmore	U10-APW-72 Birch Canyon
JO	182	Ut-Fi-10	NE $\frac{1}{4}$, Sec. 27, T11S, R 3W			
JO, PM	183	Ut-Br-1	SW $\frac{1}{4}$, Sec. 9, T19N, R 7W			
JO	184	Ut-Br-2	NW $\frac{1}{4}$, Sec. 10, T14N, R 7W			
PM, JO	185	Ut-Br-3	SW $\frac{1}{4}$, Sec. 24, T14N, R12W			
JO	186	Ut-Br-4	SW $\frac{1}{4}$, Sec. 30, T14N, R11W			
JO	187	Ut-Br-5	SE $\frac{1}{2}$, Sec. 26, T16S, R29E			
JO	188	Ut-Br-6	SE $\frac{1}{4}$, Sec. 33, T15N, R30E			
PM, JO	189	Ut-Br-7	SW $\frac{1}{4}$, Sec. 15, T47N, R15W			
PM, JO	190	Ut-Br-8	NW $\frac{1}{4}$, Sec. 24, T 9N, R10W			
JO	191	Ut-Br-9	NW $\frac{1}{4}$, Sec. 4, T 9N, R16W			
PE, JO	192	Ut-Ve-1	SE $\frac{1}{4}$, Sec. 6, T13S, R25E	BLM	Vernal	U8-R-11 Boulevard
PE, JO, JS	193	Ut-Ve-2	SW $\frac{1}{4}$, Sec. 19, T13S, R25E			
PE, JO, JS	194	Ut-Ve-3	SE $\frac{1}{4}$, Sec. 15, T16S, R22E			
PE, JO	195	Ut-Ve-4	SE $\frac{1}{4}$, Sec. 35, T16S, R22E			
PE, JS, JO	196	Ut-Ve-5	NW $\frac{1}{4}$, Sec. 13, T15S, R24E	BLM	Vernal	U8-R-40 McCook
PE, JO	197	Ut-Ve-6	SE $\frac{1}{4}$, Sec. 32, T13S, R24E			
PE, JO	198	Ut-Ve-7	SE $\frac{1}{4}$, Sec. 9, T15S, R22E			
PE, JO	199	Ut-Du-1	SW $\frac{1}{4}$, Sec. 22, T 6S, R 5W			
PE, JO	200	Ut-Du-2	SW $\frac{1}{4}$, Sec. 7, T 6S, R 4W			
PE, JO	201	Ut-Ve-8	SE $\frac{1}{4}$, Sec. 23, T12S, R21E			
JO	202	Ut-Ve-9	NW $\frac{1}{4}$, Sec. 4, T11S, R21E			
PE, JO203	203	Ut-Du-3	NE $\frac{1}{4}$, Sec. 36, T 3S, R 6W			
PM, JO	204N	Ne-Au-1	NE $\frac{1}{4}$, Sec. 17, T18N, R49E			
PM, JO	205	Ne-Au-2	SW $\frac{1}{4}$, Sec. 11, T22N, R42E			
PM, JO	206	Ne-Au-3	NW $\frac{1}{4}$, Sec. 14, T22N, R42E			
PM, JO	207	Ne-Au-4	SW $\frac{1}{4}$, Sec. 9, T18N, R48E			
PM, JO	208	Ne-Au-5	NE $\frac{1}{4}$, Sec. 24, T18N, R49E			
PM, JO	209	Ne-Ey-11	NW $\frac{1}{4}$, Sec. 24, T11N, R59E			
PM, JO	210	Ne-Ey-12	SW $\frac{1}{4}$, Sec. 19, T11N, R60E			
JO	211	Ne-Ey-13	NE $\frac{1}{4}$, Sec. 25, T12N, R59E			
PM, JO	212	Ne-Ey-14	NE $\frac{1}{4}$, Sec. 35, T12N, R59E			
	213	Ut-Mo-213	Sec. 32, T33S, R25E			
	214	Ut-Mo-214	NE $\frac{1}{4}$, Sec. 31, T33S, R26E			

215	Ut-Pr-215	NW $\frac{1}{4}$, Sec. 10, T16S, R13E
216	Ut-Pr-216	NE $\frac{1}{4}$, Sec. 6, T15S, R12E
217	Ut-Pr-217	SW $\frac{1}{4}$, Sec. 8, T14S, R11E
218	NM-So-7	S $\frac{1}{4}$, Sec. 19, TS, R 6W
219	NM-So-8	NW $\frac{1}{4}$, Sec. 8, T 2S, R 6W
220	NM-So-9	NW $\frac{1}{4}$, Sec. 26, T 4S, R 6W
221	NM-So-10	NW $\frac{1}{4}$, Sec. 16, T 4S, R 6W
222	NM-So-11	NW $\frac{1}{4}$, Sec. 8, T 2S, R 4W
223	NM-So-12	SE $\frac{1}{4}$, Sec. 14, T 2S, R 5W
224	NM-Ga-1	NW $\frac{1}{4}$, Sec. 33, T13N, R12W
225	NM-Ga-2	SW $\frac{1}{4}$, Sec. 6, T14N, R15W
226	NM-Ga-3	NE $\frac{1}{4}$, Sec. 24, T14N, R16W
227	NM-Ga-4	Sec. 8, T13N, R14W
228	NM-Ga-5	SW $\frac{1}{4}$, Sec. 28, T14N, R14W
229	Ut-Mo-9	SE $\frac{1}{4}$, Sec. 30, T41N, R25E
230	Ar-Hu-230	NW $\frac{1}{4}$, Sec. 3, T25N, R12E
231	Ar-Hu-4	N $\frac{1}{2}$, Sec. 21, T25N, R10W
232	Ar-Hu-5	NW $\frac{1}{4}$, Sec. 34, T27N, R 8W
233	Ar-Hu-6	NE $\frac{1}{4}$, Sec. 17, T25N, R 9W
234	Ar-Se-1	SE $\frac{1}{4}$, Sec. 19, T21N, R 9W
235	Ar-Se-2	NW $\frac{1}{4}$, Sec. 28, T22N, R 8W
236	Ar-Wi-236	SW $\frac{1}{4}$, Sec. 14, T24N, R 2E
237	Ar-Wi-237	NE $\frac{1}{4}$, Sec. 17, T24N, R 3E
238	Ar-F1-238	W $\frac{1}{2}$, Sec. 27, T25N, R 4E
239	Ar-F1-239	SE $\frac{1}{4}$, Sec. 16, T23N, R 8E
240	Ar-GC-1	NW $\frac{1}{4}$, Sec. 25, T29N, R 2E
241	Ar-GC-2	NW $\frac{1}{4}$, Sec. 25, T29N, R 2E
242	Ut-S1-242	NE $\frac{1}{4}$, Sec. 3, T 4S, R 6W
243	Ut-S1-243	SW $\frac{1}{4}$, Sec. 5, T 4S, R 6W
244	Ut-S1-244	NW $\frac{1}{4}$, Sec. 8, T 4S, R 5W
245	Ut-S1-245	SE $\frac{1}{4}$, Sec. 34, T 4S, R 5W
246	Ut-S1-246	NE $\frac{1}{4}$, Sec. 30, T 3S, R 7W
247	Ut-S1-247	NW $\frac{1}{4}$, Sec. 33, T 3S, R 7W
248	Ne-E1-248	SW $\frac{1}{4}$, Sec. 9, T25N, R56E
249	Ne-E1-249	NE $\frac{1}{4}$, Sec. 29, T25N, R57E
250	Ne-E1-250	NE $\frac{1}{4}$, Sec. 21, T25N, R57E

251	Ne-E1-251	SE $\frac{1}{4}$, Sec. 16, T37N, R63E				
252	Ne-E1-252	SE $\frac{1}{4}$, Sec. 3, T36N, R62E				
253	Ne-E1-253	NW $\frac{1}{4}$, Sec. 15, T33N, R55E				
254	Ut-Fi-254	NW $\frac{1}{4}$, Sec. 1, T11S, R 3W				
255	Ut-Fi-255	SW $\frac{1}{4}$, Sec. 11, T12S, R 3W	BLM	Fillmore	U10-APW-72	Birch Canyon
256	Ut-Fi-256-c	Sec. 26, T 9S, R 7W	BLM	Murray	U2-R-156	Government Creek
257	Ut-Fi-257	NW $\frac{1}{4}$, Sec. 36, T 9S, R 8W				
258	Ut-Fi-258	NW $\frac{1}{4}$, Sec. 26, T10S, R 7W	BLM	Murray	U2-R-12	Ekker
259	Ut-Fi-259	NW $\frac{1}{4}$, Sec. 30, T10S, R 3W	BLM	Murray	U2-R-49	Look Out
260	Ut-Fi-260	NW $\frac{1}{4}$, Sec. 2, T10S, R 4W	BLM	Murray		Boulder Bum
261	Ut-Fi-261	NW $\frac{1}{4}$, Sec. 28, T28S, R 8W	BLM	Fillmore	413	Porcupine
262	Ut-Fi-262	NE $\frac{1}{4}$, Sec. 27, T28S, R 8W	BLM	Fillmore	399	Porcupine
263	Ut-Fi-263	NE $\frac{1}{4}$, Sec. 33, T27S, R 8W	BLM	Fillmore	468	Shag Hollow
264	Ut-Fi-264	NW $\frac{1}{4}$, Sec. 34, T27S, R 8W	BLM	Fillmore	468	Shag Hollow
265	Ut-Fi-265	SE $\frac{1}{4}$, Sec. 28, T28S, R 8W				
266	Ut-Fi-266	SW $\frac{1}{4}$, Sec. 22, T28S, R 7W	BLM	Fillmore	430	Indian Creek
267	Ut-Fi-267	SE $\frac{1}{4}$, Sec. 18, T28S, R 6W	BLM	Fillmore	433	Indian Creek
268	Ut-Fi-268	SW $\frac{1}{4}$, Sec. 21, T30S, R15W	BLM	Fillmore	404	Jocky
269	Ut-Fi-269	NE $\frac{1}{4}$, Sec. 29, T30S, R15W	BLM	Fillmore	416	Jocky
270	Ut-CC-270	NE $\frac{1}{4}$, Sec. 33, T30S, R16W	BLM	Cedar City	U4-R-75	Pine Valley
271	Ut-Fi-271	SW $\frac{1}{4}$, Sec. 1, T27S, R 9W	BLM	Fillmore	43R-15	Daily Ridge
272	Ut-Fi-272	NE $\frac{1}{4}$, Sec. 11, T30S, R18W	BLM	Fillmore	437	Sheep Creek
273	Ut-Fi-273	NW $\frac{1}{4}$, Sec. 12, T30S, R18W	BLM	Fillmore	437	Sheep Creek
274	Ut-Fi-274	W $\frac{1}{2}$, Sec. 25, T30S, R17W	BLM	Fillmore	458	Pinto Creek
275	Ut-CC-275	SE $\frac{1}{4}$, Sec. 30, T31S, R 9W	BLM	Cedar City	U4-R-1	Willow Spring
276	Ut-CC-276	NE $\frac{1}{4}$, Sec. 34, T33S, R13W	BLM	Cedar City	466	Perrywell
277	Ne-Lv-277	NW $\frac{1}{4}$, Sec. 7, T35S, R71E	BLM	Las Vegas	N5-R-7	Taylor
278	Ne-Lv-278	NE $\frac{1}{4}$, Sec. 2, T 4S, R70E	BLM	Las Vegas	477	Cove Springs
279	Ne-Lv-279	SE $\frac{1}{4}$, Sec. 32, T 3S, R71E	BLM	Las Vegas	N5-R-478	Enterprise
280	Ne-Lv-280	NW $\frac{1}{4}$, Sec. 32, T 3S, R71E	BLM	Las Vegas	N5-R-478	Enterprise
281	Ne-Lv-281	SE $\frac{1}{4}$, Sec. 1, T 2S, R70E	BLM	Las Vegas	N5-R-11	Mahogany Hill
282	Ut-CC-282	NW $\frac{1}{4}$, Sec. 9, T43S, R12W	BLM	Cedar City	485	Little Creek Mountain
283	Ar-StG-283	NE $\frac{1}{4}$, Sec. 13, T41N, R 8W	BLM	St. George	279	Lost Spring Mtn.
284	Ar-StG-284	SE $\frac{1}{4}$, Sec. 14, T36N, R 6W	BLM	St. George	402	T. Jensen
285	Ar-StG-285	SE $\frac{1}{4}$, Sec. 1, T35N, R 6W	BLM	St. George	A1-R-33	Jensen
286	Ar-StG-286	NE $\frac{1}{4}$, Sec. 11, T35N, R11W	BLM	St. George	374	Poverty Mtn.

287	Ar-StG-287	NW $\frac{1}{4}$, Sec. 27, T35N, R11W	BLM	St. George	374	Poverty Mtn.
288	Ar-StG-288	NE $\frac{1}{4}$, Sec. 26, T35N, R11W	BLM	St. George	369	Upper Sullivan Draw
289	Ar-StG-289	NE $\frac{1}{4}$, Sec. 1, T35N, R11W	BLM	St. George	374	Poverty Mtn.
290	Ar-StG-290	NW $\frac{1}{4}$, Sec. 26, T39N, R13W	BLM	St. George	382	Little Wolf
291	Ar-StG-291	NW $\frac{1}{4}$, Sec. 30, T40N, R11W	BLM	St. George	A1-R-61	---
292	Ar-StG-292	NW $\frac{1}{4}$, Sec. 6, T39N, R12W	BLM	St. George	A1-R-378	---
293	Ut-Pr-293	SW $\frac{1}{4}$, Sec. 6, T17S, R 8E	BLM	Price	U7-R-89	Huntington Creek
294	Ut-Ri-294	NW $\frac{1}{4}$, Sec. 28, T32S, R10E	BLM	Richfield	435	Airplane Springs
295	Ut-Ri-295	SE $\frac{1}{4}$, Sec. 8, T26S, R 1E	BLM	Richfield	69	Praetor Slopes
296	Ut-Pr-296	SW $\frac{1}{4}$, Sec. 28, T14S, R 9E	BLM	Price	U7-R-137	Pinnacle
297	Ut-Mo-297	SW $\frac{1}{4}$, Sec. 30, T28S, R24E	BLM	Monticello	316	Redd Ranches
298	Ut-Mo-298	NW $\frac{1}{4}$, Sec. 30, T32S, R22E	BLM	Monticello	308	Shay Mesa
299	Ut-Mo-299	NW $\frac{1}{4}$, Sec. 30, T32S, R22E	BLM	Monticello	308	Shay Mesa
300	Ut-Mo-300	SW $\frac{1}{4}$, Sec. 15, T43N, R23E	FS	---	---	Nr. Peter's Point
301	Ut-Mo-301	NW $\frac{1}{4}$, Sec. 24, T32S, R23E	BLM	Monticello	324	Peter's Point
302	Ut-Mo-302	SE $\frac{1}{4}$, Sec. 11, T33S, R23E	BLM	Monticello		Airport
303	Ut-Mo-303	SE $\frac{1}{4}$, Sec. 12, T37S, R25E	BLM	Monticello	U6-R-66	Bug Point
304	Ut-Mo-304	SE $\frac{1}{4}$, Sec. 12, T37S, R25E	BLM	Monticello	U6-R-66	Bug Point
305	Ut-Mo-305	SE $\frac{1}{4}$, Sec. 27, T36S, R25E	BLM	Monticello	292	Table Top
306	Ut-Mo-308	NW $\frac{1}{4}$, Sec. 20, T35S, R22E	BLM	Monticello	U6-R-18	Bushy Basin
307	Ut-Mo-307	NW $\frac{1}{4}$, Sec. 25, T36S, R23E	BLM	Monticello	U6-R-3	Alkali Point
308	Ut-Mo-308	NE $\frac{1}{4}$, Sec. 11, T40N, R24E				
309	NM-Fa-309	NW $\frac{1}{4}$, Sec. 23, T32N, R13W	BLM	Farmington	NM-7-R-24	Myers
310	NM-Fa-310	NE $\frac{1}{4}$, Sec. 15, T31N, R12W	BLM	Farmington	NM-7-R-152	Robb Brothers
311	NM-Fa-311	SE $\frac{1}{4}$, Sec. 2, T30N, R13W	BLM	Farmington	NM-7-R-363	Sowers
312	NM-Fa-312	SE $\frac{1}{4}$, Sec. 11, T29N, R 8W	BLM	Farmington	NM-7-R-158	Pat Montoya
313	NM-Fa-313	NW $\frac{1}{4}$, Sec. 5, T28N, R 7W	BLM	Farmington	NM-7-R-209	P. Montoya
314	NM-Fa-314	Center, Sec. 7, T31N, R9W	BLM	Farmington	NM-7-R-93	Blancett Connen
315	NM-Fa-315	SE $\frac{1}{4}$, Sec. 33, T32N, R 9W	BLM	Farmington	NM-7-R-364	Blancett
316	NM-Fa-316	SE $\frac{1}{4}$, Sec. 14, T31N, R 9W	BLM	Farmington	NM-7-R-208	R. Vlibarri
317	NM-Fa-317	SW $\frac{1}{4}$, Sec. 13, T32N, R 9W	BLM	Farmington	NM-7-R-333	Blancett
318	Ut-Mo-318	NE $\frac{1}{4}$, Sec. 19, T37S, R19E	BLM	Monticello	U6-R-4	Cyclone Flats
319	Co-Cr-319	SW $\frac{1}{4}$, Sec. 2, T 4N, R100W	BLM	Craig	C1-499	---
320	Co-Cr-320	SE $\frac{1}{4}$, Sec. 10, T 4N, R98W	BLM	Craig	C1-510, 511, 512	---
321	Co-Cr-321	SW $\frac{1}{4}$, Sec. 20, T 2N, R100W	BLM	Craig	C1-510, 511, 512	---
322	Ut-Ve-322	NW $\frac{1}{4}$, Sec. 24, T14S, R22E	BLM	Vernal		Pine Springs Cooperative

323	Ut-Ve-323	SE $\frac{1}{4}$, Sec. 18, T13S, R25E	BLM	Vernal	U8-R-11	Boulevard
324	Ut-Ve-324	NE $\frac{1}{4}$, Sec. 13, T 3N, R23E	BLM	Vernal	U8-R-77	Diamond Mtn.
325	Ut-Ve-325	SE $\frac{1}{4}$, Sec. 27, T 3N, R22E	BLM	Vernal	U8-R-76	Brush Creek
326	Ut-Ka-326	SW $\frac{1}{4}$, Sec. 33, T42S, R4 $\frac{1}{2}$ W	BLM	Kanab	---	Mackelprang
327	Ut-Ka-327	Center, Sec. 12, T43S, R4W	BLM	Kanab	U11-R-42	Vermillion 2
328	Ut-Ka-328	SW $\frac{1}{4}$, Sec. 34, T38S, R 4E	BLM	Kanab	U11-R-29	Airport Flat
328B	Ut-Ka	NE $\frac{1}{4}$, Sec. 4, T29S, R 4E				
329	Ut-Ka-329	NW $\frac{1}{4}$, Sec. 8, T36S, R 4E				
330	Ut-Ka-330	NW $\frac{1}{4}$, Sec. 26, T37S, R 4W	BLM	Kanab	U11	Sheep Flat-Juniper
331	Ut-Ka-331	SE $\frac{1}{4}$, Sec. , T38S, R 3W				
332	Ut-Ka-332	SE $\frac{1}{4}$, Sec. 13, T34S, R 6W	BLM	Richfield	U5-44	Tarantual Mesa
333	Co-Du-333	NE $\frac{1}{4}$, Sec. 31, T37N, R20W	BLM	Durango	C4-R-279	Hovenweep
334	Co-Du-334	SE $\frac{1}{4}$, Sec. 18, T37N, R19W	BLM	Durango	C4-R-236	Helper
335	Co-Du-335	SW $\frac{1}{4}$, Sec. 31, T38N, R10W	BLM	Durango	C4-R-158	Green
336	Co-Du-336	SW $\frac{1}{4}$, Sec. 11, T37N, R18W	BLM	Durango	C4-R-235	Heller
337	Co-Du-337	SE $\frac{1}{4}$, Sec. 11, T36N, R18W	BLM	Durango	C4-R-159	Grand
338	Co-Du-338	SW $\frac{1}{4}$, Sec. 5, T45N, R13W	BLM	Durango	C4-R-176	Grammer
339	Co-Mo-339	NW $\frac{1}{4}$, Sec. 32, T48N, R10W	BLM	Montrose	C3-R-138	Garrison
340	Co-Mo-340	SE $\frac{1}{4}$, Sec. 22, T48N, R11W	BLM	Montrose	C3-R-137	Paxton
341	Co-Mo-341	SE $\frac{1}{4}$, Sec. 25, T48N, R11W				
342	Co-Mo-342	SW $\frac{1}{4}$, Sec. 31, T49N, R11W	BLM	Montrose	C3-R-346	Roubideau 2
343	Co-Mo-343	SW $\frac{1}{4}$, Sec. 12, T49N, R12W	BLM	Montrose	C3-R-78	Roubideau 1
344	Co-Mo-344	SE $\frac{1}{4}$, Sec. 30, T50N, R12W	BLM	Montrose	C3-313	Monetor Mesa
345	Co-Mo-345	NW $\frac{1}{4}$, Sec. 8, T50N, R12W	BLM	Montrose	C3-R-313	Davis
346	Co-Mo-346	NW $\frac{1}{4}$, Sec. 11, T50N, R13W	BLM	Montrose	C3-283	Mesa
347	Co-GJ-347	NW $\frac{1}{4}$, Sec. 33, T14S, R100W	BLM	Grand Junction	C7-R-263	Dominguez
348	Co-GJ-348	NW $\frac{1}{4}$, Sec. 9, T13S, R102W	BLM	Grand Junction	C7-R-7	Timber Ridge
349	Co-Nat.Mon.	SE $\frac{1}{4}$, Sec. 10, T11S, R101W				
350	Ne-Ely-350	SE $\frac{1}{4}$, Sec. 9, T15N, R63E				
351	Ne-Ely-351	NE $\frac{1}{4}$, Sec. 10, T15N, R63E				
352	Ne-Ely-352	SE $\frac{1}{4}$, Sec. 3, T15N, R63E				
353	Ne-Ely-353	NE $\frac{1}{4}$, Sec. 2, T15N, R63W				
354	Ne-Ely-354	Sec. 36, T13N, R65E				
355	Ne-Ely-355	Sec. 31, T13N, R66E				
356	Ne-Ely-356	Sec. 33, T13N, R66E				
357	Ne-Ely-357	Sec. 34, T13N, R66E				
358	Ne-Ely-358	Sec. 25, T21N, R69E				

359	Ar-Fs-359	NW $\frac{1}{4}$, Sec. 3, T39N, R 1E	FS	Jacob Lake	---	Ryan Allotment
360	Ar-Fs-360	NW $\frac{1}{4}$, Sec. 16, T39N, R 1E	FS	Jacob Lake	---	Ryan Allotment
361	Ar-StG-361	NW $\frac{1}{4}$, Sec. 3, T39N, R 3E	BLM	St. George	A1-398	Sand Hill
362	Ar-FS-362	NE $\frac{1}{4}$, Sec. 6, T15N, R 7E	FS	Beaver Creek	---	Apache Maid (Round Mt.)
363	Ar-FS-363	SW $\frac{1}{4}$, Sec. 28, T16N, R 7E	FS	Beaver Creek	---	Apache Maid (Table Top)
364	Ar-FS-364	NE $\frac{1}{4}$, Sec. 15, T16N, R 7E	FS	Beaver Creek		Apache Maid (Table Top)
365	Ar-FS-365	SE $\frac{1}{4}$, Sec. 18, T21N, R 9E	FS	Elden		Cosnino
366	Ar-FS-366	NW $\frac{1}{4}$, Sec. 34, T21N, R10E	FS	Elden		Angell
367	Ar-Hu-367	NE $\frac{1}{4}$, Sec. 17, T31N, R 7W	BIA	Haulapai	1954	Prospect Ridge
368	Ar-Hu-368	Center, Sec. 20, T31N, R7W	BIA	Haulapai	1964	Burn and Chain
369	Ar-Hu-369	SE $\frac{1}{4}$, Sec. 1, T30N, R 8W	BIA	Haulapai	1962	Prospect Ridge
370	Ar-Hu-370	NW $\frac{1}{4}$, Sec. 33, T30N, R 7W	BIA	Haulapai	1957	Laguna
371	Ar-Hu-371	NW $\frac{1}{4}$, Sec. 35, T27N, R 8W	BIA	Haulapai	1959	20-Pine
372	Ar-Hu-372	SW $\frac{1}{4}$, Sec. 27, T26N, R13W	BIA	Haulapai	1963	No. Steer Past
373	Ar-FS-373	NE $\frac{1}{4}$, Sec. 23, T13N, R 7E	FS	Beaver Creek		Mud Tanks
374	Ar-FS-374	NE $\frac{1}{4}$, Sec. 17, T13N, R 7E	FS	Beaver Creek		Mud Tanks
375	Ut-Ka-375	SW $\frac{1}{4}$, Sec. 5, T25N, R 5E	FS	Chalendar		Dog Knobs
376	Ut-Ka-376	NW $\frac{1}{4}$, Sec. 9, T24N, R 3E	FS	Chalendar		Smoot Lake
377	Ut-Fi-377	SW $\frac{1}{4}$, Sec. 13, T27S, R 9W	BLM	Fillmore	U3-R-50	Cedar Cove
378	Ut-Fi-378	SE $\frac{1}{4}$, Sec. 35, T28S, R15W	BLM	Fillmore	U3-R-55	Bucket Ranch
379	Ut-CC-379	Center, Sec. 12, T31S, R18W	BLM	Cedar City	U4-R-187	Arrowhead
380	Ar-Strip	SE $\frac{1}{4}$, Sec. 2, T34N, R10W	BLM	St. George	A1-R-459	Elmo Bundy
381	Ar-Strip	SE $\frac{1}{4}$, Sec. 10, T39N, R13W	BLM	St. George	399	Black Rock Tank
382	Ar-Strip	SW $\frac{1}{4}$, Sec. 3, T35N, R 9W	BLM	St. George	298	Bundy Trumble
383	Ar-Strip	SW $\frac{1}{4}$, Sec. 34, T37N, R 9W	BLM	St. George	A1-R-544	Hurricane Rim
384	Ar-Strip	NE $\frac{1}{4}$, Sec. 1, T31N, R13W	BLM	St. George	427	Twin Point
385	Ne-Lv-385	NW $\frac{1}{4}$, Sec. 25, T 4S, R65E	BLM	Las Vegas	N5-R-6	Oak Springs
386	Ne-Lv-386	NE $\frac{1}{4}$, Sec. 11, T 5S, R70E	BLM	Las Vegas	432	Beaver Dam Flats
387	Ne-Lv-387	SW $\frac{1}{4}$, Sec. 17, T 6S, R69E	BLM	Las Vegas	N5-R-10	Sheep Springs
388	Ne-Elko-388	SW $\frac{1}{4}$, Sec. 20, T31N, R63E	BLM	Elko	N1-R-442	Spruce Mt. A
389	Ne-Elko-389	NE $\frac{1}{4}$, Sec. 11, T31N, R64E				
390	Ut-Mo	SE $\frac{1}{4}$, Sec. 35, T33S, R18E				
391B	Ut-Mo	Sec. 32, T33S, R18E	BLM	Monticello	277	Dark Canyon #2
391C	Ut-Mo	Sec. 32, T33S, R18E	BLM	Monticello	277	Dark Canyon #2
392	Ut-Ka-392	NW $\frac{1}{4}$, Sec. 12, T37S, R 1W				
393	Ut-Ka-393	SE $\frac{1}{4}$, Sec. 28, T35S, R 4E				
394	Ut-Ka-394	SW $\frac{1}{4}$, Sec. 17, T39S, R 4E				

395	Ut-Ka-395	SE $\frac{1}{4}$, Sec. 14, T39S, R 4E				
396	Ut-Ka-396	NW $\frac{1}{4}$, Sec. 27, T43S, R 8W				
397	Ut-Ka-397	SW $\frac{1}{4}$, Sec. 9, T42S, R 7W				
398	Hopi-398	SW $\frac{1}{4}$, Sec. , T28N, R20E	BIA	Hopi	#1	
399	Hopi-399	SE $\frac{1}{4}$, Sec. 14, T28N, R20E	BIA	Hopi	#5	
400	Hopi-400	111°30' - 36°26'				
401	Nav.-401	110°46' - 36°25'	BIA	Tuba City	#4,5	Cedar Ridge
402	Nav.-402	111°03' - 36°28'	BIA	Tuba City	#2	White Mesa
403	Nav.-403	110°48' - 36°35'	BIA	Tuba City	#12	P. Begay
404	Nav.-404	110°32' - 36°32'	BIA	Tuba City	#11	Eli Crank
405	Nav.-405	110°25'W- 36°34'N				
406	Ut-Mo	SW $\frac{1}{4}$, Sec. 24, T35S, R24E				
407	Ut-Mo	SW $\frac{1}{4}$, Sec. 21, T39S, R18E				
	S-10	NE $\frac{1}{4}$, Sec. 32, T13N, R19E	FS	Pinedale		Linden-Fence Tank
	S-11	NE $\frac{1}{4}$, Sec. 36, T12N, R18E	FS	Pinedale		West Sundown
	S-12	NW $\frac{1}{4}$, Sec. 13, T11N, R20E	FS	Pinedale		Dodson
	S-13	NW $\frac{1}{4}$, Sec. 12, T11N, R21E	FS	Pinedale		Gov't Tanks
	S-14	SW $\frac{1}{4}$, Sec. 2, T10N, R23E	FS	Lakeside		Ortega Lake
	N-1B&C	SW $\frac{1}{4}$, Sec. 19, T 6N, R 7W	BIA	Chinle	#1 & #10	Willie Shirley & Denet
	N-2	NE $\frac{1}{4}$, Sec. 6, T 6N, R 7W	BIA	Chinle	#2	Mike Johnson Tsosie
	N-3	SE $\frac{1}{4}$, Sec. 24, T 6N, R 9W	BIA	Chinle	#3	Henery Draper
	N-4	NE $\frac{1}{4}$, Sec. 10, T25N, R10W	BIA	Ft. Defiance	#3	Dick Deal
	N-5	SE $\frac{1}{4}$, Sec. 6, T24N, R 9W	BIA	Ft. Defiance	#1	Bomniface Bonnie
	N-6	NE $\frac{1}{4}$, Sec. 15, T24N, R27E	BIA	Ft. Defiance	#5	Bomniface Bonnie
	N-7	NW $\frac{1}{4}$, Sec. 14, T23N, R27E	BIA	Ft. Defiance	#4	Bent Knee
	N-8	Center, Sec. 10, T22N, R29E	BIA	Ft. Defiance	#37,38,39,42,52,53,55	
	N-9	SW $\frac{1}{4}$, Sec. 33, T22N, R30E	BIA	Ft. Defiance	#20,21	Kimball Pinto
	A-15	NE $\frac{1}{4}$, Sec. 32, T 8N, R18E	BIA	Ft. Apache	450-3308	
	A-16	SE $\frac{1}{4}$, Sec. 6, T 7N, R20E	BIA	Ft. Apache	450-1739	#1
	A-17	SW $\frac{1}{4}$, Sec. 33, T 8N, R20E	BIA	Ft. Apache	450-1739	#2
	A-18	SE $\frac{1}{4}$, Sec. 12, T 8N, R20E	BIA	Ft. Apache	450-1739	#5
	Z-19	NW $\frac{1}{4}$, Sec. 20, T10N, R20W	BIA	Zuni	8 & 9	---
	Z-20	NE $\frac{1}{4}$, Sec. 2, T 8N, R19W	BIA	Zuni	10	---

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